TEKTRONIX

Circuit Concepts

CRT

Power Supply

Horizontal
Amplifier

Vertical
Amplifier

Sweep
Generator

Trigger

Oscilloscope Trigger Circuits

OSCILLOSCOPE TRIGGER CIRCUITS

BY

HAROLD MAGEE

CIRCUIT CONCEPTS

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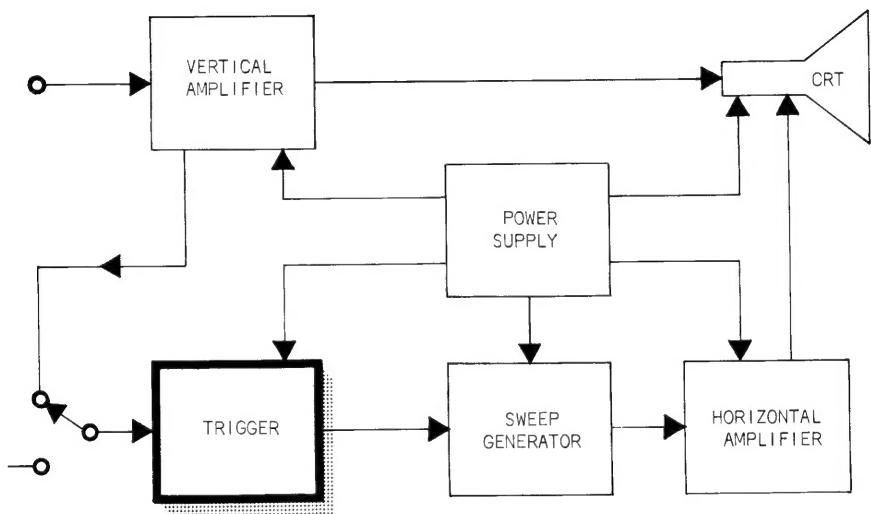
INTRODUCTION

In a study of conventional oscilloscopes, the various circuits of the instrument will fall into a few general groups. These may be listed as: cathode-ray tube, power supply, vertical amplifier, horizontal amplifier, sweep generator, and the trigger circuit.

Each part performs an important function and, in part, determines the final performance of the instrument.

THE
CATHODE-RAY
TUBE

The cathode-ray tube displays light on a two-dimensional phosphor screen which conveys intelligence in the form of graphs, alphanumerics or picture images. Graphical presentations offer an analytical approach in that actual measurements can be taken with a graticule along the screen's "x" and "y" axis.

CRT
electron
gun

The CRT electron gun is sealed inside an envelope and a vacuum is created to minimize collisions between free gas particles and the electron beam. High-voltage power supplies connected to the CRT create controllable electrostatic fields which accelerate free electrons from a heated cathode to form an electron beam. The beam of electrons then transit an electron lens which converges or focuses the beam on a phosphor screen. When the high-velocity electrons collide with phosphor atoms at the focal point, photons of light are emitted towards the viewer.

electrons

The positioning of the point light source on the screen is accomplished by varying the electrostatic field between a set of "x" and "y" deflection plates. This permits the electron beam to create a display anywhere within the viewing screen area. Since electrons have an extremely small mass, they can be deflected or scanned over the entire screen area millions of times per second. This permits the

real time

viewer to observe changing phenomena in real time.

The CRT must not present an undue loading on either the vertical or horizontal amplifier or require a greater dynamic-deflection voltage range than the amplifiers can supply. In practice, the CRT and deflection amplifiers must be designed together for maximum performance and efficiency.

VERTICAL
AMPLIFIER

The vertical amplifier of an oscilloscope determines the useful bandwidth and gain of the instrument. The vertical amplifier may take four general forms: a fixed vertical that cannot be changed, a complete vertical in a plug-in form that may be changed, or a fixed main amplifier that is preceded by a plug-in preamplifier that can be changed to have different characteristics. An additional type of instrument takes the drive directly to the CRT plates without passing through any type of amplifier.

The general purpose oscilloscope is intended to provide a faithful display of an input pulse. For meaningful results, displayed waveforms must contain few aberrations and these must be but a few percent of the total waveform amplitude.

The following characteristics are important in describing the performance of a vertical amplifier.

bandwidth

Bandwidth (BW) describes the gain versus frequency limits between an upper and lower frequency. These frequencies are the points where voltage gain drops to 70.7% of maximum (3 dB down). To have a lower frequency -3 dB point, the scope must be AC coupled. The low-frequency response is that of a high-pass RC filter. The upper-frequency rolloff follows a curve that usually approximates the gaussian error curve. Amplifier low-frequency response extends to DC. Therefore, the upper-frequency -3 dB point describes the bandwidth for a DC-coupled instrument.

risetime

Risetime (T_R) indicates the transient response characteristics of a vertical amplifier. One measures risetime along the leading edge of a displayed voltage step. This specifies transition time from 10% to 90% of maximum voltage. Bandwidth of a general-purpose

instrument can usually be related to the
risetime by the equation BW · T_R = .35.

deflection
factor

Deflection factor describes the voltage required
at the input to deflect the trace one CRT
division and is expressed as V/div.

THE
HORIZONTAL
AMPLIFIER

X-Y
presentation

Y-T displays

The horizontal amplifier converts the sweep-generator
time-base ramp to a driving signal for the horizontal
deflection plates of the CRT. In the process it
must transform the single-ended input signal to an
amplified push-pull signal with minimum departure
from linearity and at the required deflection factor.
In those oscilloscopes offering (X-Y) presentations
at the full bandwidth of the instrument, the
horizontal amplifier must exhibit a frequency
response comparable to that of the vertical amplifier.
In conventional Y-T displays, it provides direct-
current (DC) level controls, through which the overall
gain may be multiplied by factors of one or more,
providing a sweep speed increase by the same factor.

SWEEP
GENERATOR

time
measuring
reference

The sweep generator produces a sawtooth waveform
that is processed by the horizontal amplifier to
deflect the CRT electron beam across the face of
the CRT. The major function of the sweep generator
is to produce a sawtooth waveform with the proper
rate-of-rise amplitude and linearity that will
provide a suitable time measuring reference for the
cathode-ray oscilloscope.

TRIGGER
CIRCUIT

changing
input
signals

The input signal may have a wide variety of shapes
and amplitudes, many of which are unsuitable as
sweep initiating triggers. For this reason these
signals are first applied to a trigger circuit where
they are converted to pulses of uniform amplitude
and shape. The addition of a trigger circuit makes
it possible to start the sweep with a pulse that
has a constant size, eliminating variations of the
sweep-circuit operation caused by changing input
signals. This extra circuit allows the operator to
use either slope of the waveform to start the sweep,
select any voltage level on the rising or falling
slope of the waveform, and, in some instances,
filter out selected frequencies of the input signal
with greater ease and repeatability.

TO VERTICAL
AMPLIFIER

| TRIGGER TAKEOFF CIRCUITRY | | INPUT COUPLING CIRCUITRY | INPUT AMPLIFIER | PULSE GENERATOR |

EXTERNAL
INPUT

TO SWEEP
GENERATOR
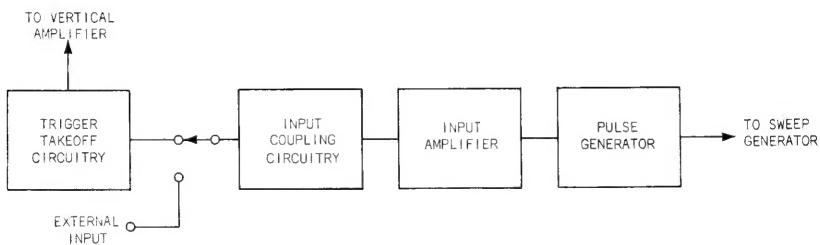
Fig. 2-1. The trigger circuit in the oscilloscope.

2

TRIGGER CIRCUITS

block
diagram

The general block diagram (see Fig. 2-1) of an
oscilloscope triggering circuit can be separated into
four basic parts: vertical-amplifier trigger takeoff
circuitry, input-coupling circuitry, input amplifier
and pulse generator. The complexity of each section
is determined by the triggering requirements of the
oscilloscope. These requirements are basically
established by the vertical amplifier characteristics
and the sweep speeds available from the horizontal
amplifier.

trigger
takeoff
circuitry

Any oscilloscope that can be triggered internally
from the viewed signal must have some type of
coupling to transmit a sample of the vertical signal
to the input of the trigger circuit. This circuitry
may take several forms depending on performance
requirements of the oscilloscope. It may vary from
a very simple divider to a complex push-pull amplifier.

requirement

In each case the general requirements of the circuit
are the same. The takeoff circuitry must act as a
buffer, to keep the trigger circuitry from changing
the operation of the vertical amplifier and yet pass
the vertical-amplifier signal to the trigger circuit,
without undue amplitude or frequency distortion for
the operating ranges of the oscilloscope trigger.
The trigger takeoff circuitry may also have to change
voltage and gain levels between the vertical amplifier
and the trigger. In addition, the trigger circuitry

noise

must not add noise or other interfering signals to
the triggering signal at an amplitude sufficient to
cause erratic triggering. Stable operation of the
trigger circuit, when triggering internally, is in
part, dependent on the stability of the takeoff
circuit.

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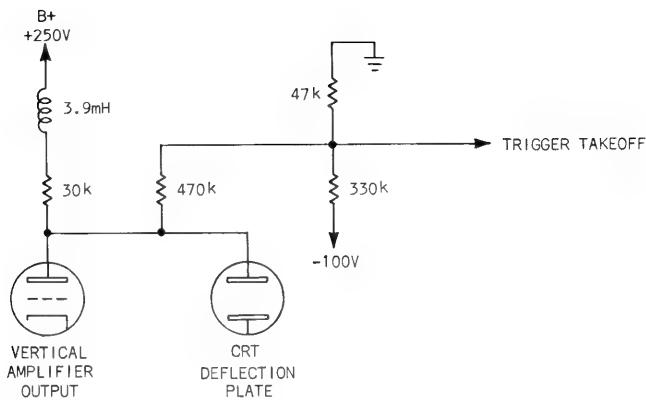
Fig. 2-2.   Simple trigger-takeoff circuit.
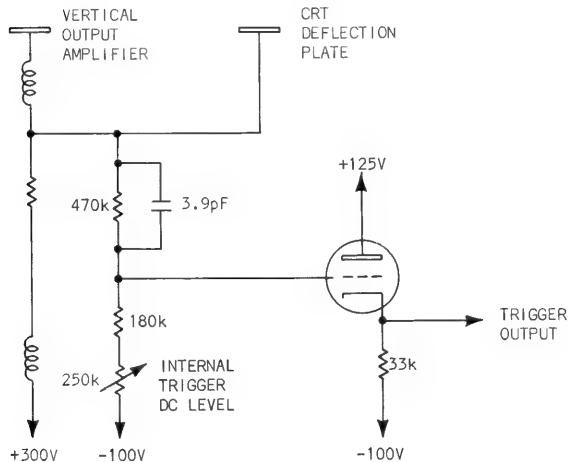
Fig. 2-3.   Trigger-takeoff circuit for
oscilloscope without delay line.

trigger
takeoff

Fig. 2-2 illustrates one of the simple types of trigger takeoff. This circuit takes the output directly from one CRT plate in a low frequency oscilloscope. There is no delay line in the instrument, so it can be triggered from the vertical output stage with no need for additional gain. The divider network is not compensated for high frequencies and the loading on one side of the vertical amplifier is not a problem at low frequencies. The network provides an attenuated output near zero volts with the trace centered on the cathode-ray tube.

low-
frequency

high-
frequency

Fig. 2-3 is a trigger takeoff circuit from an oscilloscope without a delay line. The takeoff point is at the CRT deflection plate so no amplification is needed. The divider has a 3.9 pF capacitor to compensate it for high frequencies and the resistive load is less than the low-frequency circuit in Fig. 2-2. An adjustment is added to set the cathode-follower output at zero volts with the trace centered. The cathode follower reduces the loading on the vertical amplifier and provides a low-impedance output to the trigger circuit to retain the high-frequency component of the triggering signal. In this circuit, both alternating current (AC) and DC triggering-signal amplitudes receive the same attenuation.
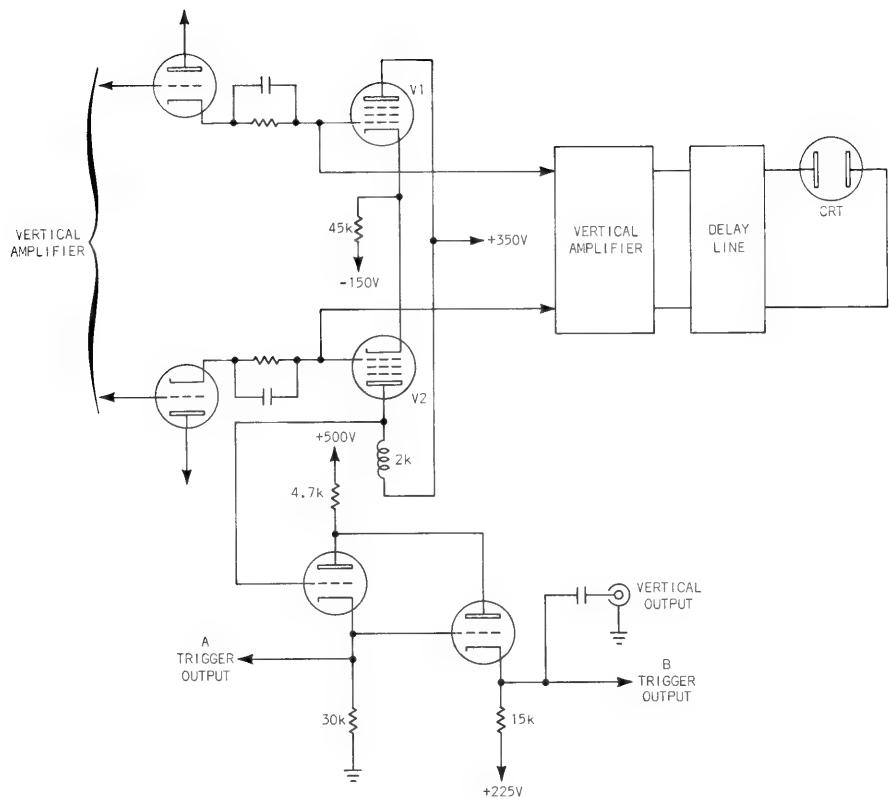
Fig. 2-4. High frequency pickoff circuit
with a delay line.

Fig. 2-4 is the schematic of a pickoff circuit from a high-frequency oscilloscope with a delay line. There is a low impedence-takeoff point from each side of the vertical amplifier followed by cathode followers to minimize loading and provide an equal load to each side of the amplifier.

Fig. 2-4   The oscilloscope referred to in Fig. 2-4 has a wide-frequency response and the takeoff system must pass these frequencies to the trigger circuit, when the instrument is operated in either the triggered or synchronized mode. V1 and V2 provide added amplification for the signal.

The plate load for V2 is an inductive resistance to provide good high-frequency response. An advantage of push-pull, trigger-takeoff operation is that it provides common-mode signal rejection so that variations due to DC level changes and power supply variations are not transmitted to the trigger circuit. A cathode follower is used after the amplifier stage to reduce loading, produce a low-impedance output, and retain the wide bandpass necessary for the trigger-input signal. A second cathode follower provides an AC-coupled, vertical-signal output at the front panel of the oscilloscope and is a takeoff point for a second trigger circuit, if the instrument has a delayed sweep.

delay line   The function of the delay line is to provide enough time delay for the vertical signal so that it will not reach the vertical-deflection plates of the CRT before the trigger and sweep circuits have been activated by the input signal. If there is not enough delay in the vertical amplifier it will not be possible to see the first part of a fast signal on the CRT.

In order for the delay to be effective, the trigger signal must be taken from some point that precedes the vertical delay.
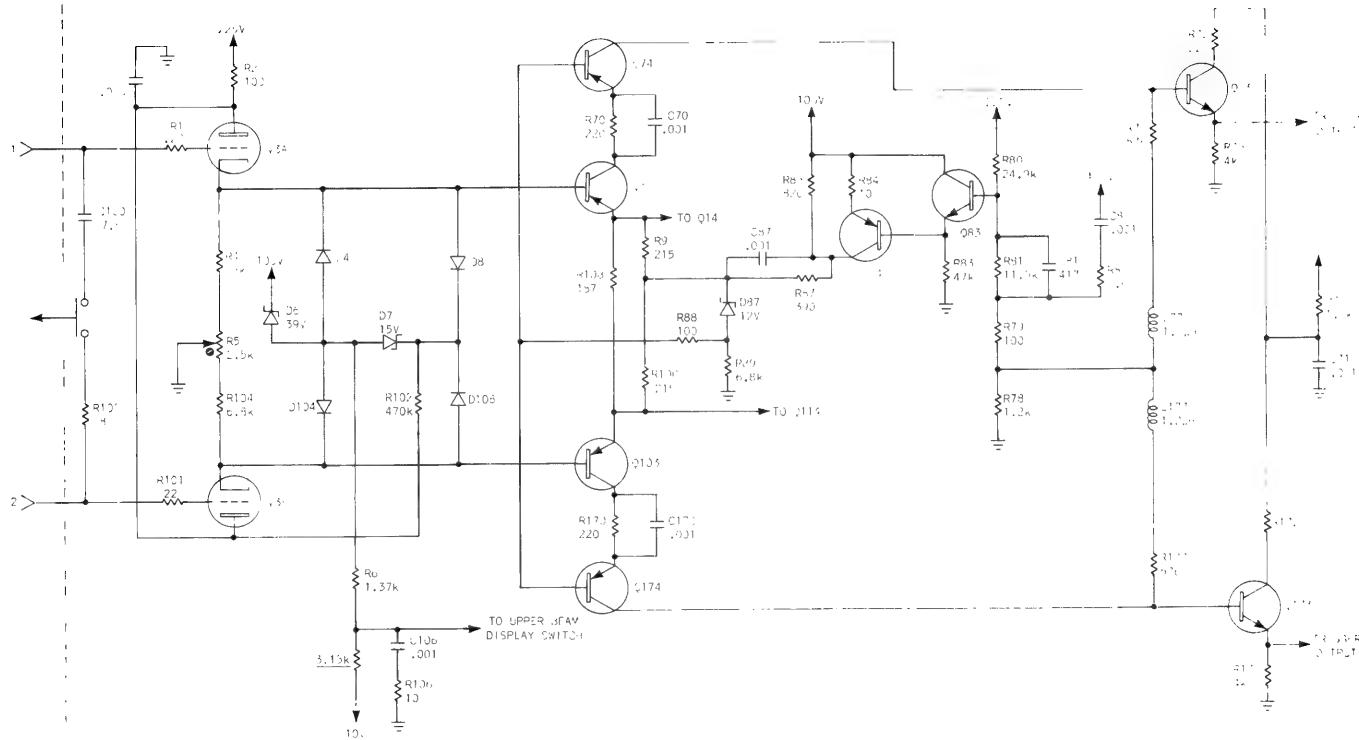
Fig. 2-5.   Complex-takeoff circuit with
push-pull output signal.

Fig. 2-5 illustrates a takeoff circuit that is more
complex. This circuit produces a push-pull output
signal to the trigger-input amplifier. Transistors
Q3 and Q103 operate as emitter followers for the
vertical amplifier and as the lower half of cascode
amplifiers for the takeoff circuit. The upper half
of each cascode amplifier drives an emitter follower
which sends a signal to the trigger-input amplifier.
The output level of the cascode amplifier is sensed
and amplified by regulator Q83/Q84 and applied to the
cascode amplifier input to cancel out the change,
which returns the circuit's average-output level to
the same point. The voltage variation then appears
across Q74 and Q174. This keeps common-mode signals
from upsetting the levels, at the trigger circuit,
when different plug-ins are inserted in the
oscilloscope, or when the common mode signal-level
shifts.

Some multi-channel instruments have the option of
triggering from one channel, this enables the operator
to start the sweep each time with the same signal and
makes accurate time measurements between signals on
the other channels possible in either alternate or
chopped modes of operation. Plug-ins that have this
capability may have an output on the front panel that
can be connected to the external-trigger input on the
main frame to provide this mode of operation in
instruments lacking an internal connection.

cascode
amplifier

"plug-in"
levels

single
channel,
trigger
takeoff

external
trigger

Since this trigger takeoff point is closer to the
input of the oscilloscope, it is necessary to add more
amplification, than when the pickoff is from a higher
amplifier   signal level. The added amplification requirements
bandpass   may result in a more restricted bandpass from this
amplifier. A typical amplifier bandpass is shown in
Fig. 2-6.
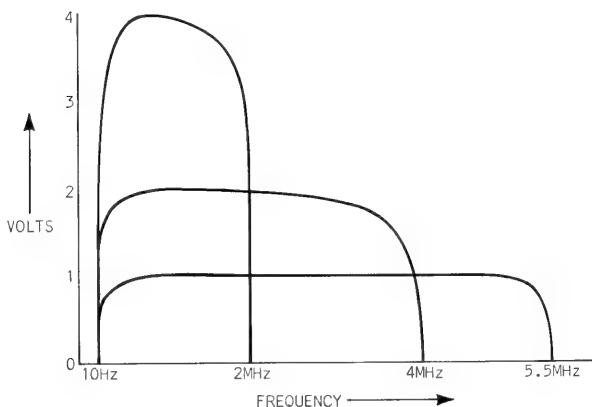
Fig. 2-6. Typical amplifier bandpass.

The Fig. 2-6 also shows that the amplifier has a
dynamic range limitation. This requires that high-
frequency triggering and extremely low-frequency or
DC   DC triggering should be done from the main amplifier
triggering   triggering point. Some single-channel amplifiers,
however, do cover the entire triggering range of the
oscilloscope. In most cases the positioning control
for the individual channel comes after the pickoff
point in the amplifier, so the trigger-output level
from a single channel is not changed by positioning.
As a result of this, DC triggering does not appear to
work normally.

normal
triggering

DC
triggering
from
Channel 1

In the internal-normal, DC-coupled mode, the triggering point or trace-starting point is related to a specific level on the CRT screen. As the waveform is positioned up and down on the screen, the triggering point changes on the waveform, always being related to the same vertical level on the screen. If the waveform is placed so that it is all above or all below this point, triggering will cease. An instrument that is DC triggered from Channel 1 will not act this way, because the level information is added to the vertical signal after the Channel 1-pickoff point and position does not affect the triggering point. See Fig. 2-7.
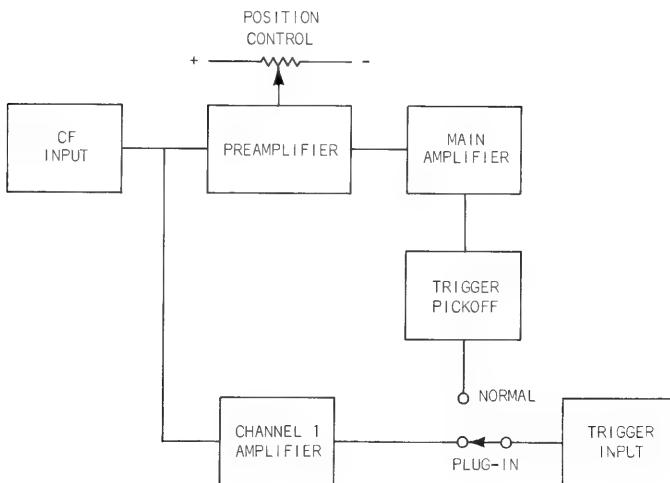
Fig. 2-7. Triggering Position/Control.

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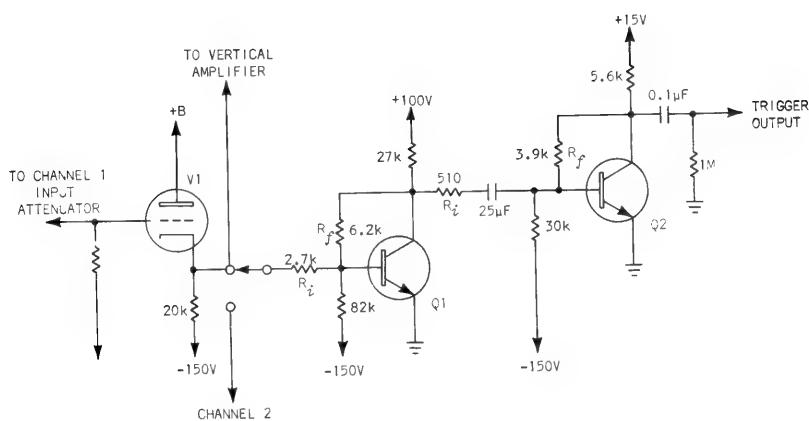
Fig. 2-8.   Individual channel trigger-pickoff
            circuit.

amplifier gain

Fig. 2-8 is a simple type of individual-channel, trigger pickoff. The amplifier is composed of two operational-amplifier stages. The gain of the amplifier is closely approximated by $\frac{R_f}{R_i}$. In the first stage the gain is $\frac{6.2K \ (R_f)}{2.7K \ (R_i)} \simeq 2.3$. The gain of the second stage is frequency dependent, as the 25 µF capacitor-reactance adds to the 510 Ω R_i-resistance. At a frequency where the reactance of the capacitor is low enough to be neglected, the gain of the amplifier is $\frac{3900 \ (R_f)}{510 \ (R_i)} \simeq 7.6$. Multiplying this gain, by the first-stage gain, results in a gain of about 17.5. Reactance of the 25 µF capacitor causes the response of the amplifier to rolloff. At a frequency of 10 Hz the signal is down 3 dB. When used with a "plug-in" with a basic sensitivity of 50 mV per centimeter, it has an output in excess of 0.5 volts per centimeter. The amplifier is AC coupled as discussed above, which limits its low frequency response but has the advantage of being less susceptible to overloading due to DC offsets at the input of the channel.

trigger coupling circuitry

Early oscilloscopes used only AC coupling between the trigger-pickoff circuit and the trigger-input amplifier. This type of coupling was satisfactory in many cases, but as sweep generators became capable of generating slower sweeps, it was necessary to add a coupling circuit that would respond to lower frequencies. The addition of DC coupled-vertical amplifiers also made it convenient to be able to trigger at a set level on the screen.

Other refinements were added. AC low frequency reject made it possible to trigger on high frequency signals in the presence of low frequency signals; it also was a triggering aid when two input channels, switching alternately, were added to the input of the vertical amplifier. Some oscilloscopes also have a high frequency reject position. This allows the operator to reject high frequency signals or transients and start the sweep on lower frequency signals only.
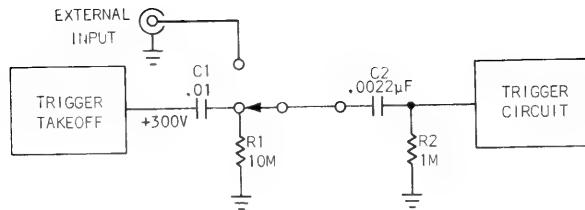
Fig. 2-9. An AC coupling circuit.
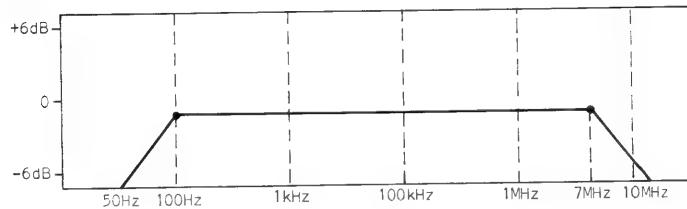
Fig. 2-10. AC-coupled trigger response.
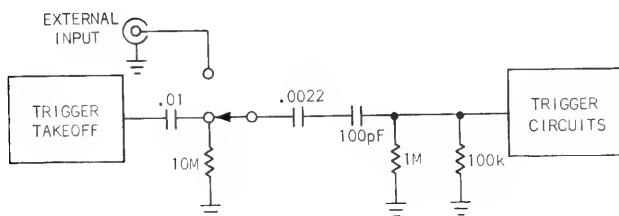
Fig. 2-11. Low frequency reject circuit.

A typical AC coupling circuit is shown in Fig. 2-9.

resistance-
capacitance
circuits

There are two series resistance-capacitance (RC) circuits, the one composed of C1/R1 is only used to keep C2 from charging to +300 volts and discharging through any circuit connected to the External trigger input when the trigger-source switch is switched to the External position. C2/R2 are the primary coupling and limit the low frequency operation of the circuit. High frequency response is limited primarily by stray circuit capacities. A typical circuit may have –3 dB response points at 100 Hz and 7 MHz as shown in Fig. 2-10; the actual rolloff frequencies will vary with instrument type. The low frequency –3 dB point of the amplifier is equal to the frequency that causes the capacitive reactance (X_C) of C2 to equal the resistance of R2. The actual frequency may vary somewhat as the two components are not precision parts. This does not mean that triggering stops at these frequencies, but that increased signal amplitude will be required below these frequencies for stable triggering. The RC rolloff at the low frequency end of the bandpass is 6 dB per octave, which is the same as 20 dB per decade. The high frequency end of the bandpass is determined by many factors and is not an RC rolloff, but more closely approaches a Gaussian rolloff. The factors which regulate the high frequency rolloff are wiring capacitances, lead inductances and the high frequency characteristics of the amplifying device.

An example of a low frequency-reject circuit is shown in Fig. 2-11. This may also be called AC Fast on some instruments.

low
frequency-
reject

alternate
mode

In this circuit a 100 pF capacitor has been added in series with the input and the 1 M input resistor of the trigger circuit has been paralleled with a 100 K resistor. This time constant change causes the lower 3 dB frequency to be shifted from 100 to 10 kHz. This attenuates low frequency-sine waves and differentiates low frequency-square waves or pulses. Because of this it is possible to use a dual trace instrument more easily in the alternate mode with the trigger signal originating from the main-vertical amplifier. The input-time constant is selected so that the square wave caused by switching from channel to channel is differentiated, but recovers to a quiescent level during the sweep holdoff period
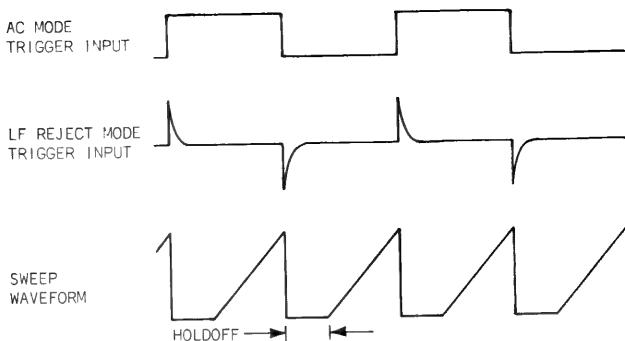
Fig. 2-12. Waveform produced by selecting
alternate mode triggering.

See Fig. 2-12. During this time the trigger circuit
may produce several outputs, however the signal
produced at the end of holdoff is caused by a signal
applied to either of the channels and is not a result
of alternate switching waveforms.
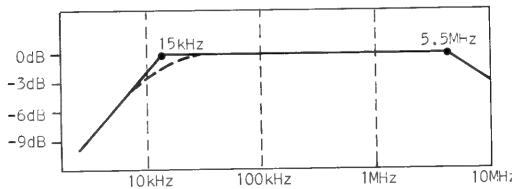
Fig. 2-13. Low frequency reject-trigger
response.

Another aid to triggering is to position the traces
as closely together as possible for the measurement
being made. This reduces the amplitude of channel-
switching transition fed into the trigger circuit.

Fig. 2-13 shows a typical response for the trigger-
circuit input in the low frequency-reject mode.

Since the range of AC triggering drops off rapidly at frequencies below 100 Hz, it may be difficult to trigger on slowly changing waveforms with AC coupling. The addition of DC coupling extends the low frequency triggering capabilities to the slowest waveforms. A typical DC coupling circuit is shown in Fig. 2-14.
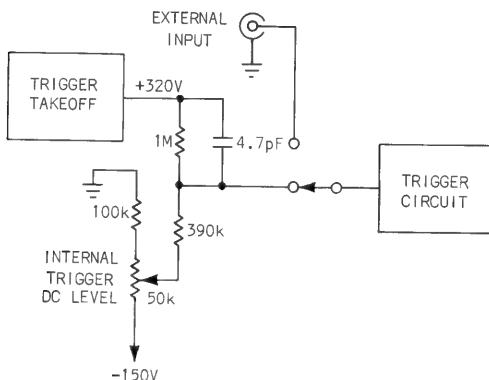

Fig. 2-14. DC-coupling circuit.

The output of the trigger takeoff circuit has a level of about +320 V, when the cathode-ray tube trace is centered. This level must be reduced so that the input to the trigger circuit is zero volts with the trace centered. This makes zero volts-input from the internal circuit correspond to zero volts-input internal from the external input. In Fig. 2-14 a resistive trigger DC divider is used to accomplish this. An adjustment, level adjust internal trigger DC Level Adjust, is used to set the divider output to zero volts, when the CRT trace is centered. A small capacitor, C_1, provides a first-order higher frequency compensation of the divider. The signal amplitude is reduced by the divider to about one third of the equivalent AC amplitude, which reduces the DC mode sensitivity.

The DC mode of operation is affected by any change
in the DC level at the divider output. This could be
resistance changes due to temperature variations,
vertical amplifier level changes caused by changing
"plug-ins" or vertical amplifier drift because of
aged components. Voltage changes are minimized by
using precision resistors with low temperature-
coefficients and by using compensating devices in
the pickoff circuits, like regulators or pentode
amplifiers, where small changes in plate-supply
voltages cause little change in plate current and
output voltage.

voltage changes

Instruments that have very high frequency triggering
capabilities may have a high frequency-reject position
on the trigger mode switch. This makes it possible
to reject high frequencies in the presence of low
frequency signals for more stable triggering at the
lower frequency. It is particularly useful in areas
where fast transients are present. A typical trigger
response is shown by Fig. 2-15.

**high-
frequency
(HF) reject
mode**
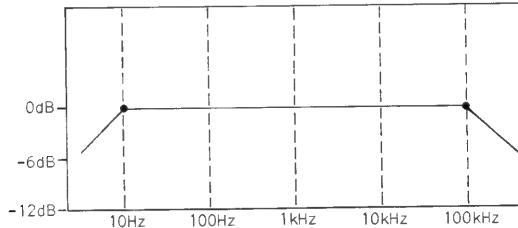
Fig. 2-15. High frequency reject-trigger
response.

When the instrument is switched to HF reject, a
band width-reduction circuit is added to attenuate
frequencies above about 100 kHz. A capacitor may be
added almost any place in the circuit to reduce
bandpass. One circuit is shown in Fig. 2-16.

**function of
a trigger
circuit**

The function of the trigger circuit is to generate
an output pulse whenever the input voltage level
reaches a desired level and is changing in the desired
direction. To do this a level detector, a slope
detector and a pulse generator are used.
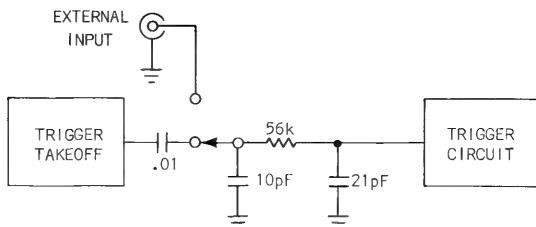
Fig. 2-16. High frequency reject circuit.

The trigger circuit of an oscilloscope generates
pulses which activate the sweep generator. The output
of the sweep generator is then amplified and applied
to the horizontal deflection plates to produce a
visible trace on the face of the CRT. The start of
a display must coincide with the same point on the
vertical deflection signal with each successive sweep
if the waveform under observation is to appear stable
on the CRT face.

Two general modes of operation are employed to
establish the coincidence of horizontal and vertical
deflection signals:

> 1. Synchronized
> 2. Triggered

synchronized
mode

In the synchronized mode, the sweep generator is made
to free-run at a frequency just below that of the
input frequency (or one of its sub-multiples). The
input signal, applied directly to the sweep generator,
then acts to accelerate the free-running condition
bringing the two frequencies into synchronization.
A control that changes the sweep hold-off time is
adjusted to synchronize the sweep.

triggered
mode

Most modern oscilloscopes are operated whenever
possible in the triggered mode. In this mode the
input signal itself (or some other time related signal)
initiates each horizontal sweep, thus assuring
coincidence of the horizontal and vertical deflection
signals. The sweep generator operates as a monostable
multivibrator and switches state only upon receipt
of an external pulse. Once triggered it completes
its cycle and returns to the original state
disregarding any triggers, which may arrive during
the cycling interval.

The input signal may have a wide variety of shapes and amplitudes, many of which are unsuitable as sweep initiating triggers. For this reason these signals are first applied to a trigger circuit, where they are converted to pulses of uniform amplitude and shape.

A typical oscilloscope trigger circuit consists of (1) an input amplifier and (2) a pulse generator (Fig. 2-17).
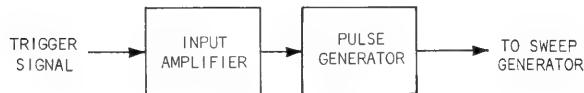
Fig. 2-17. Pulse generator and trigger circuit.

input
amplifier

The input amplifier provides a means by which the oscilloscope operator is able to select almost any point of a changing slope on the input waveform as the starting point for the horizontal sweep.

3

INPUT TRIGGERING SIGNALS

inputs

**Four sources of triggering signals are usually
available at the trigger selector switch (Fig. 3-1):
(1) INTERNAL (INT) (vertical amplifier) (2) INTERNAL
(plug-in Channel 1) (3) LINE (line voltage, 60 cycles)
and (4) EXTERNAL (EXT) (external signal required).**
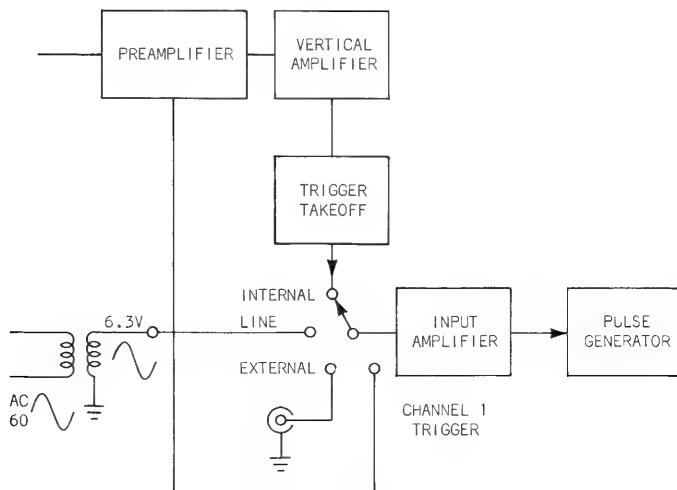
Fig. 3-1. Trigger circuit inputs.

The "INT NORMAL" or Plug-In Position is most often used. In this position, a replica of the vertical-input signal is applied to the trigger circuit. The sweep generator is thus related to the vertical waveform under observation.

"LINE"

Since many signals occur at power line frequencies, it is sometimes convenient to trigger the sweep generator at this rate. In the "LINE" position, a replica of the power line voltage, usually from a filament winding, is used as a triggering source. The 60 Hz waveform is an easy waveform to trigger on and by varying the trigger level control, it is possible for the operator to vary the relative phase of the signal being viewed and its position on the face of the CRT.

"EXT"

Occasions arise when the vertical signal must be observed in its relationship to another event, possibly occurring at a different time or frequency. This comparison can be made by using the "EXT" trigger position, which connects the trigger input amplifier to the "EXT TRIGGER" jack on the front panel. (A high input impedance reduces the input amplifier loading of the signal source.)

circuit operation

The Fig. 3-2 is a schematic of a simplified-input amplifier. This configuration is called a cathode-coupled DC amplifier, or voltage comparator. It has a high input impedance and presents a minimum load to the vertical amplifier or any circuit connected to the external trigger input. A circuit of this type may be considered a cathode follower driving a grounded grid stage, which permits the two cathodes to share the same resistor. If both tubes have the same transconductance, about one-half of the input signal will appear at the cathodes. The common mode signal appearing at the cathode subtracts from the input signal and reduces the gain of the amplifier. This characteristic results in a circuit gain of about half the expected value.
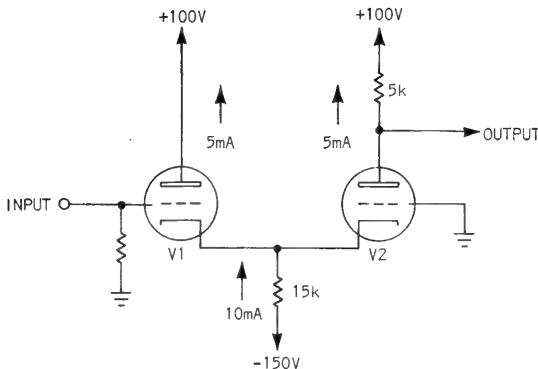
Fig. 3-2. Simplified-input amplifier.

The output of this amplifier is limited to two
extreme conditions:

the
extreme
conditions

1. Positive signals of sufficient amplitude
    cause V1 to drive V2 into cutoff. The output
    voltage then equals V2's plate supply voltage.

2. Negative signals of sufficient amplitude
    drive V1 into cutoff, and all cathode current
    passes through V2. The output voltage is
    determined by the amount of V2's plate
    current and the resistance of the plate load.

There is no phase reversal between the input and
output signal. The output varies over a set range
and cannot be driven beyond it. The amplitude of a
useful input signal is limited by the cutoff points
of V1 and V2. When the grids of V1 and V2 are at the
same voltage, the output of the circuit falls halfway
between the two output limits (in this case 75 V).

In Fig. 3-3, a variable voltage, ranging from +10 V
to -10 V is added to the grid of V2. This range is
sufficient to cut off either V1 or V2. Since the
amplifier is "long-tailed" to the negative 150 V
supply, the current through the amplifier will remain
almost constant, regardless of the setting of R1.
The output voltage of V2 however, can vary between
50 V (V1 cutoff) and 100 V (V2 cutoff). A 75 volt
output occurs when both grids are at the same level,
see Fig. 3-4. Therefore, whenever the input signal
reaches the same level set at the grid of V2, the
output from the plate of V2 will pass through the 75 V
level. In this manner the input amplifier selects a
point on an input waveform and amplifies it to a
pre-determined level (provided the amplitude of the
input voltage does not exceed the range of voltage
detector   available at R1). This provides the level detector
action   action necessary in a trigger circuit.

If it is assumed, as is true in many instruments, that
the pulse generator will produce a sweep starting
pulse, only when the output of V2 crosses the 75 V
level in a negative direction (the actual voltage
depends on the instrument); it follows that only the
negative-going portion of the input waveform will
cause this circuit to trigger a sweep, since the input
amplifier does not invert the phase of the input
signal. This provides the slope detector action
necessary in the trigger circuit.
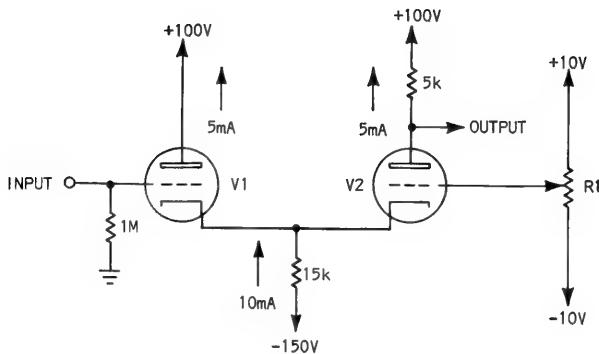
Fig. 3-3. Variable voltage supply.
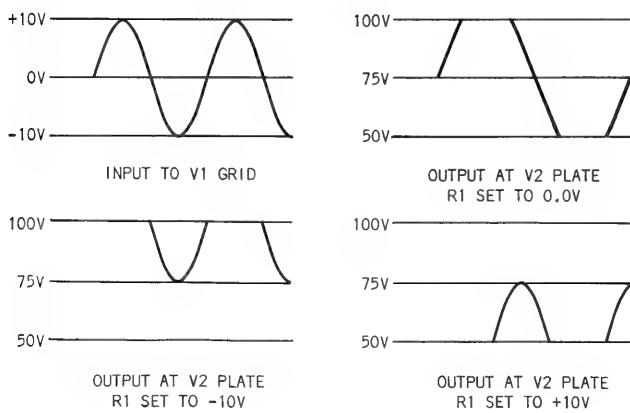
Fig. 3-4. Variable-voltage outputs.

triggering
level
control

Reversing the input connections to the grids of V1 and V2, see Fig. 3-5, reverses the phase of the output. The voltage-setting control (usually called the Triggering Level Control) is now connected to the grid of V1. The pulse generator can then be triggered by a positive-going waveform, since the input signal phase will be reversed in the plate circuit of V2.

"slope"
switch

To permit a choice of positive or negative triggering-signals, a "slope" switch is added to the circuit (Fig. 3-5). This switch couples the input signal to either grid, to produce a negative output at the plate of V2.

The Fig. 3-6 incorporates additional circuit elements. Resistor R3 limits grid current, when large-amplitude, positive input signals are applied in the external mode. A small capacitor in parallel with R3 prevents attenuation of high frequency signals.

"Miller
effect"

To provide a constant amplitude output, the input amplifier should present the same impedance to signals of either polarity. However, high frequency signals are attenuated, when applied to the grid of V2 (positive slope position) due to "Miller effect". This is feedback, coupled from plate to grid through the inter-electrode capacitance of the tube.

Signals applied to V1's grid do not experience this effect, since its plate is tied to AC ground and signals are coupled to V2 through the common cathode. However, because V2's plate must be allowed to swing if the circuit is to produce an output signal, signals applied to V2's grid suffer increasing attenuation at high frequencies through plate to grid feedback.
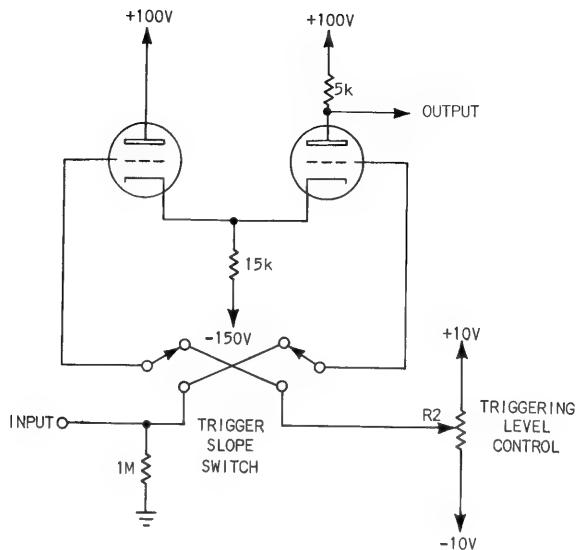
Fig. 3-5. Triggering level circuit association.
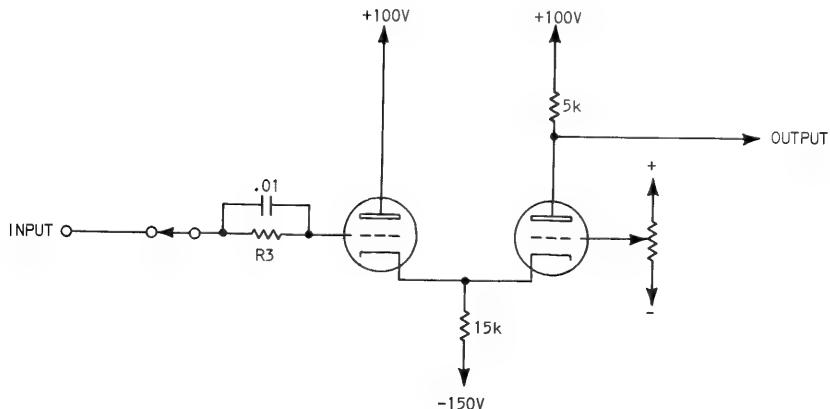
Fig. 3-6. Slope-switch circuit.

In Fig. 3-7 the circuit has been balanced by the insertion of Resistor R3 and capacitor C2 in the plate circuit of V1. C2 approximates the input capacity of the following stage. Both tubes now present the same impedance to incoming signals and the triggering characteristics of the input do not change when switching slope.

"ringing"

Resistors R1 and R2 prevent parasitic oscillations of the input amplifier and also dampen out any "ringing" in the long input leads.

Capacitor C1 improves high frequency gain by holding the grid of the control tube at AC ground and prevents it from following the cathode signal.
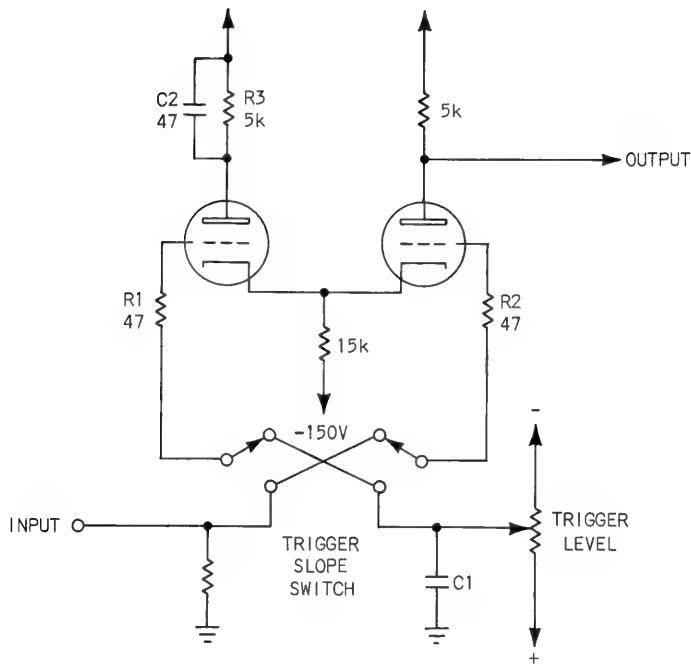
Fig. 3-7. Trigger circuit for voltage output.

Improved amplification of the triggering signal is achieved in Fig. 3-8. Here the vertical amplifier signal is applied in push-pull. Acting as a differential amplifier, the input amplifier rejects common-mode signals (hum, transients and noise common to the grids of V1 + V2) and produces a "cleaner" signal for the pulse generator.

Only the AC coupling is shown connected in push-pull, however, some oscilloscopes provide the same type of coupling in the DC position.

Small peaking coils and low-value load resistors on the plate circuits of V1 and V2 extend the high frequency response of this input amplifier.

transistor
input
amplifier

Transistorized input amplifiers require special techniques to overcome the problem presented by their low input impedance characteristic.
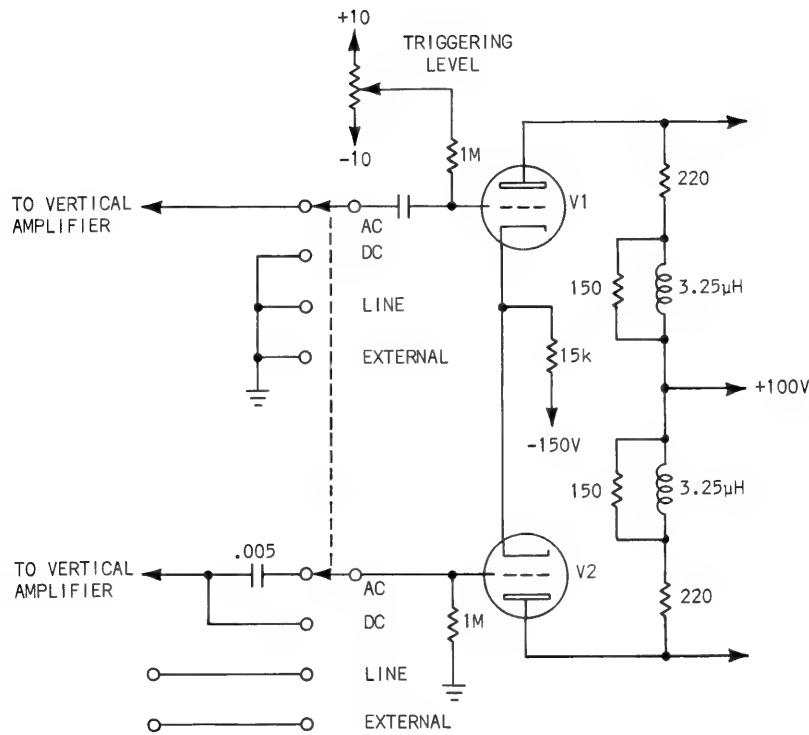
Fig. 3-8. Improved trigger circuit.

One solution to the problem is shown in Fig. 3-9. Here the triggering signals are first applied to a cathode follower, which then drives the transistorized input amplifier. A field effect transistor may be used in place of the tube for the cathode follower function.

"base
catching"

Grid limiting-resistor R1 protects V1 against positive signals of excessive amplitude. "Base catching" diodes, D1 and D2, limit the range of voltage that may be applied to the base of Q1 to prevent forward or reverse breakdown. (NOTE: Temperature compensating diodes have been eliminated for simplicity.) In this configuration, the slope switch selects the desired polarity from the output of the input amplifier.

EXT and
INT trigger

Another impedance matching technique is illustrated in Fig. 3-10. The EXT trigger connection has a high-value series resistance. The INT trigger signal is taken from a low impedance point in the vertical amplifier. This method does not provide as high an input impedance as the vacuum-tube input, but it is satisfactory for most applications. The EXT input resistor protects Q1 and Q2 against excessive input voltages, but since it attenuates signals as well, it reduces the sensitivity of the triggering circuit in the EXT mode.
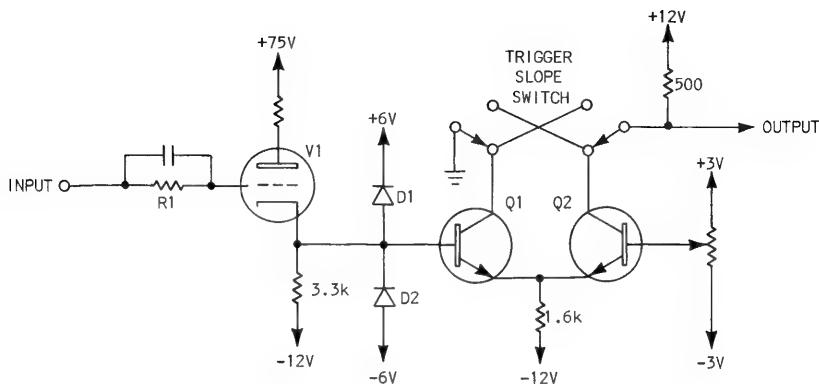
Fig. 3-9. Cathode follower input to amplifier.
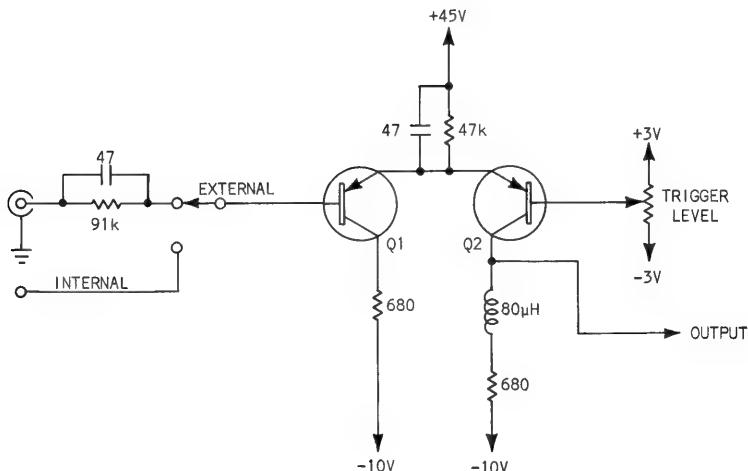
Fig. 3-10. Specialized input to amplifier.
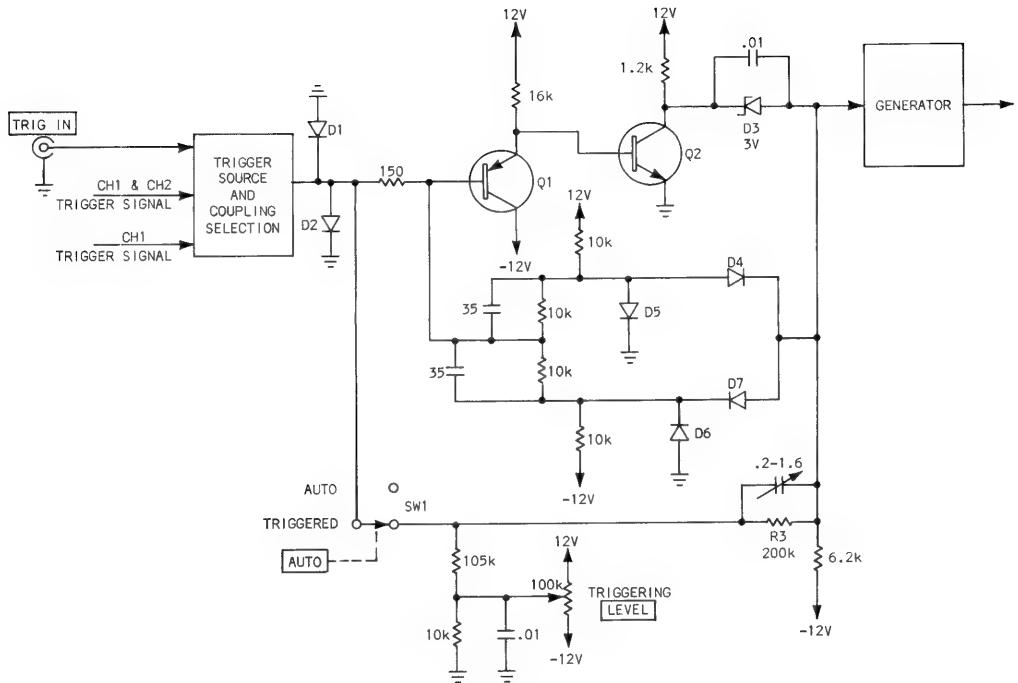
Fig. 3-11. Input with operational amplifier.

input-
operational
amplifier

In some oscilloscopes the input amplifier is classed
as an operational amplifier (Fig. 3-11).

Diodes D1 and D2 limit the amplitude of the EXT input
signal to protect transistor Q1. Zener diode D3
drops the output DC voltage level at the collector
of Q2 to zero. A portion of the output pulse is fed
back to the base of Q1 in opposite phase to the input
signal. Diodes D4, D5, D6 and D7 in conjunction with
their associated components constitute a feedback
limiter. Action of the circuit is such that the
output is held to ±1 V maximum for inputs up to ±10 V.

An advantage of this type of input amplifier lies in
its stable gain characteristic, which is independent
of change in transistor gain (Beta).
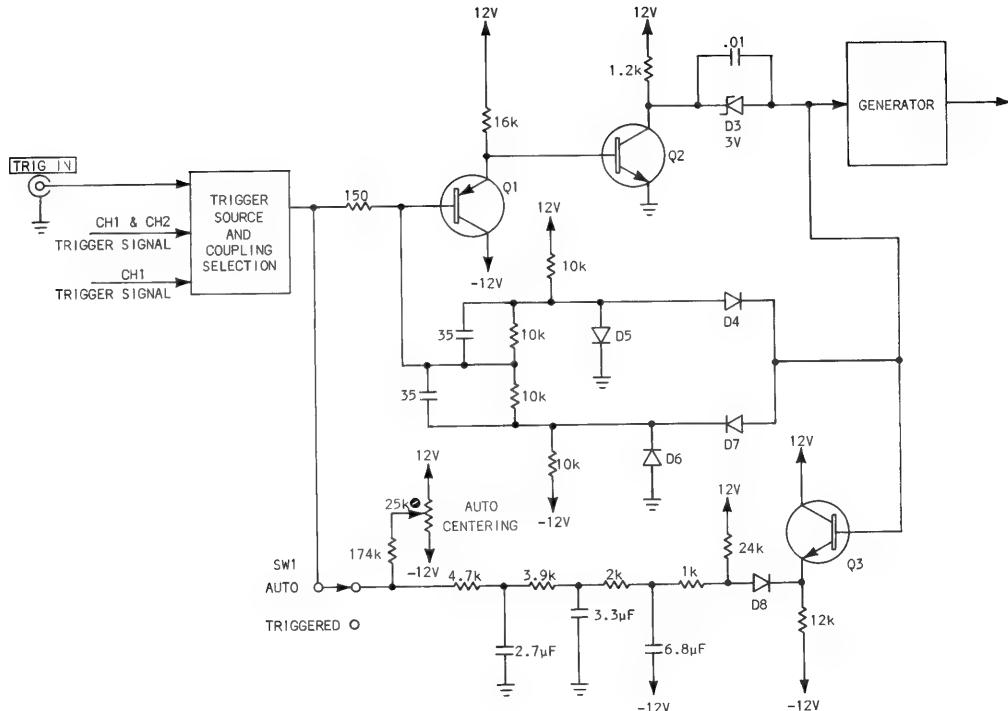
Fig. 3-12. Automatic operational amplifier.

An additional circuit, shown in Fig. 3-12, provides
the oscilloscope with an automatic mode of operation.

automatic
controlled
amplifier

When SW1 is placed in the AUTO position, feedback
resistor R3 is replaced by transistor Q3 and a 180°
phase shift network. The operational amplifier
becomes a phase shift oscillator, whose output
amplitude is still controlled by the limiter circuit.
The oscillator will free run until an input signal
of higher frequency is applied to the circuit. Such
signals will not undergo sufficient phase shift to
provide positive feedback and will suppress the
action of the oscillator. The circuit will once again
function as an operational amplifier and the input
signal will control the frequency of the pulse
generator.
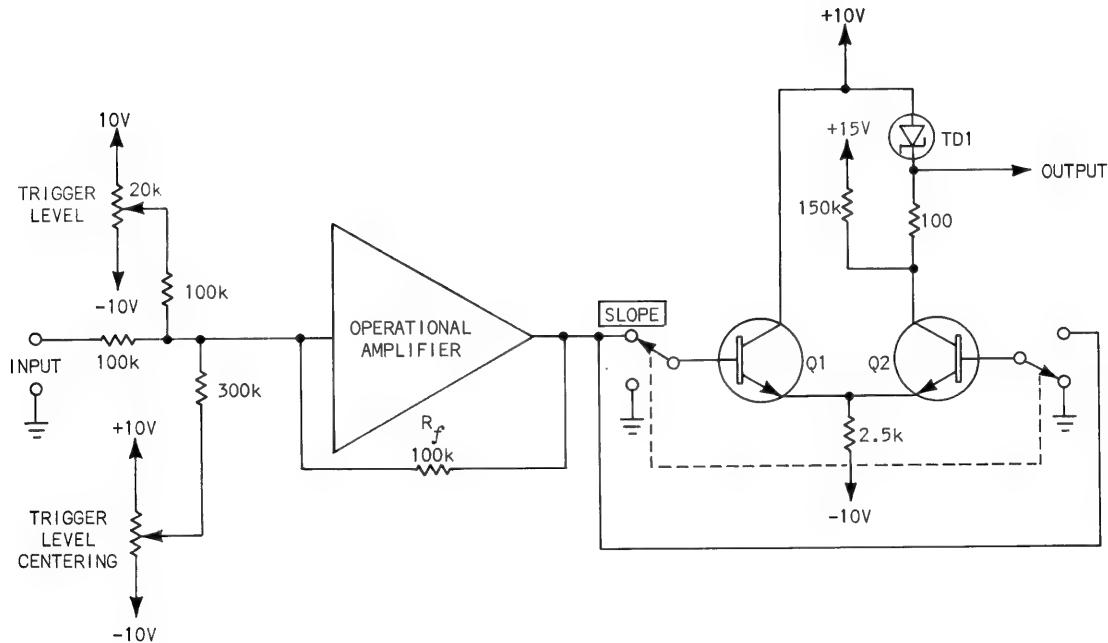
Fig. 3-13. Functional diagram of amplifier
and comparator.

level

Another version of the transistorized input amplifier
utilizes an operation amplifier and an adder circuit
(Fig. 3-13). The amplifier provides unity gain for
the input signal and the trigger LEVEL control signal,
while the trigger level-centering control signal is
reduced by 2/3. The sum of these inputs is sent to
the input amplifier/comparator and the level is
compared against the ground reference established at
the undriven base.
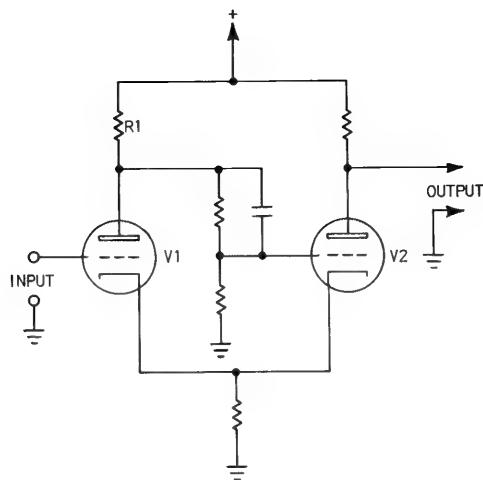
Fig. 4-1.   Schmitt multivibrator.
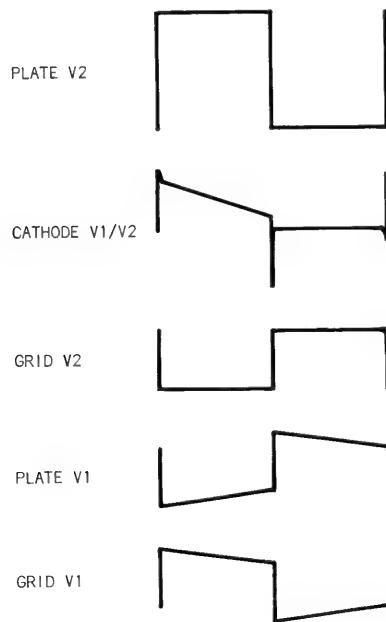
Fig. 4-2.   Waveforms of Schmitt multivibrator.

4

PULSE GENERATORS

The purpose of the pulse generator is to provide a
pulse to the sweep generator each time the signal
from the input amplifier crosses a specific voltage
level in a direction as selected by the slope.
selector. It should operate over a wide range of
environmental conditions, remain stable as components
age, regenerate the trigger quickly and respond to
all frequencies within the vertical bandpass of the
oscilloscope.

Schmitt
multivibrator

Most low frequency oscilloscopes (and some early,
high-frequency models) employ a Schmitt multivibrator
as a pulse generator (Fig. 4-1). The "Schmitt" is
a bistable multivibrator and operates as follows:

Assume V1 is conducting and V2 cut off. As the
grid of V1 goes negative in response to the
input signal, the common cathode follows. At
the same time, the positive going signal at V1's
plate is coupled to the grid of V2. This
combination of grid and cathode signals drives
V2 into full conduction, producing a negative
pulse on its plate. As the input signal returns
to its reference level (goes positive) V1 starts
to conduct again. The negative signal on its
plate is coupled to the grid of V2, driving it
sharply into cutoff. The circuit is then ready
to accept the next input signal. See Fig. 4-2.
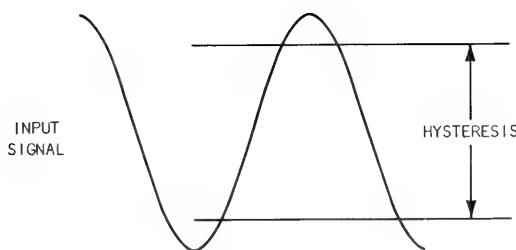
Fig. 4-3.   Hysteresis effect.
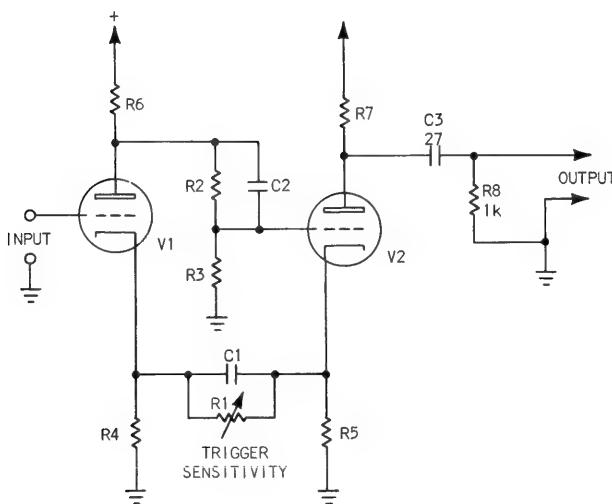
Fig. 4-4.   Hysteresis adjustment with Schmitt
multivibrator.

hysteresis   In order to produce a complete cycle (transition)
              V1's grid must first go sufficiently negative to
              start the regenerative action described above, then
              return to a sufficiently positive level to "flip" the
              multivibrator back to its original state. The voltage
              difference between these two switching levels is a
   measure of the multivibrator's "hysteresis". To
              permit control by low amplitude input signals, a
              multivibrator must therefore exhibit a low hysteresis
              characteristic. See Fig. 4-3.

              The Fig. 4-4 shows a Schmitt multivibrator that
hysteresis   permits adjustment of the circuit's hysteresis.
adjustment   Trigger sensitivity control R1, inserted between the
              cathodes of V1 and V2 now causes the cathode of the
              non-conducting tube to be at a slightly lower potential
              than that of the conducting tube and therefore biased
              closer to conduction. However, the circuit will
              become unstable if the hysteresis is reduced too far.

              Capacitor C1 maintains the voltage drop across R1 for
              an instant during transitions, keeping circuit-gain
              high and preserving the fast switching characteristics
              of the multivibrator.

              Since V2 switches between cutoff and a specific
              conducting level, the output pulse maintains the
              same amplitude and polarity, regardless of the
              amplitude of the input signal, (provided the
              period of the input signal remains greater than
              the multivibrator's transition time).

              The output pulse is processed by a differentiator,
              (R8 and C3) so that only the fast rising and falling
              portions of the waveform are passed to the sweep
              generator.
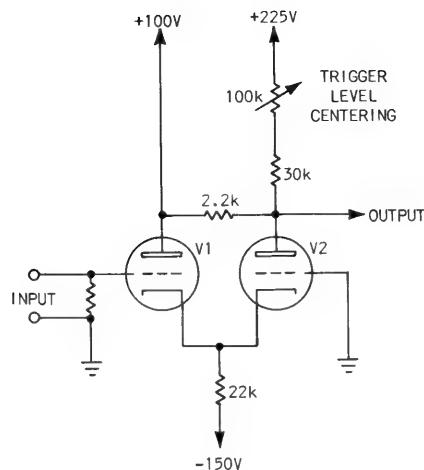
Fig. 4-5. Input amplifier.
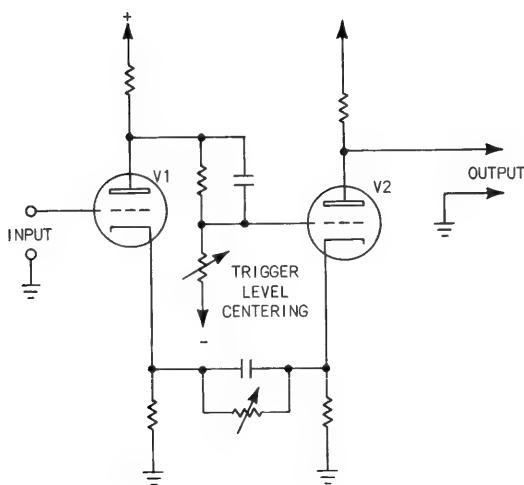
Fig. 4-6. Pulse generator.

At frequencies in the 1-3 MHz range the output pulse begins to distort, because the period of the input signal becomes less than the multivibrator cycle time and the efficiency of the Schmitt multivibrator as a pulse generator rapidly deteriorates. Therefore, oscilloscopes with this type of pulse generator are usually operated in the synchronized mode at frequencies above the 5-10 MHz range. A position is provided at the trigger mode selector switch (labeled "HF SYNC") which capacitively couples the input signal directly to the sweep generator. In this mode the sweep generator is made to synchronize with the input signal.

NOTE: The sweep generator is made to "lock in" or synchronize by adjusting the stability control.

trigger
level
centering

Stable triggering by low amplitude input signals depends on centering the output of the input amplifier about the pulse generator's hysteresis range, (switching levels).

To compensate for any mismatches between input amplifier and pulse generator in low frequency instruments, it is usually only necessary to increase the gain of the input amplifier to assure that its output crosses the hysteresis range of the pulse generator. This method is unsatisfactory in high frequency instruments, because it is difficult to get both wideband width and high gain. Because of this, a Trigger Level Centering adjustment is provided, either in the input amplifier (Fig. 4-5) or in the pulse generator (Fig. 4-6), to match the operating points of the two circuits.
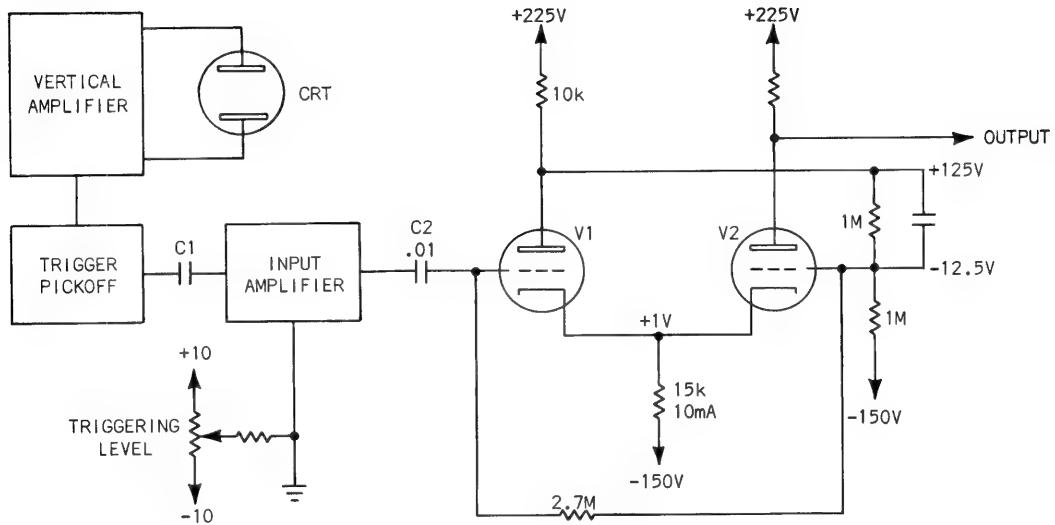
Fig. 4-7. Automatic trigger selection.

AUTOMATIC
OPERATION

If trigger circuit adjustments are not made properly
(and some of them are critical at high frequencies
and low input amplitudes) no sweep will be generated.
At the same time it may be necessary to see the input
signal to determine what adjustments are necessary to
achieve satisfactory triggering. To provide a sweep
under these circumstances, two methods are commonly
employed: The first method places the sweep generator
in a free-running condition (this method is described
in the volume on Sweep Generators). The second method
involves the trigger circuit.

automatic
trigger
mode

A position labeled AUTOMATIC is provided at the
TRIGGER MODE switch. When placed in this position,
the switch performs the following operations
(Fig. 4-7).

1. Capacitively couples the output of the
   vertical amplifier to the input amplifier
   through C1.

2. Capacitively couples the input amplifier
   to the pulse generator.

3. Connects the grids of V1 and V2 through a
   resistor.

4. Sets Trigger Level voltage at zero, (except
   in tunnel diode-pulse generators, not shown).

NOTE: This arrangement bypasses any front panel
adjustment that might be improperly set and insures
a trace regardless of whether or not a signal is
present.

Under no-signal conditions the pulse generator free-
runs at a frequency determined primarily by the time
constant of the input capacitor and added resistor.
However, when a signal is present at the input to the
oscilloscope it will feed through the capacitive
coupling from the vertical amplifier and input
amplifier. If its frequency is higher than the free-
run frequency and has sufficient amplitude, it will
control the pulse generator operation.

transistor
Schmitt
multi-
vibrator

The Schmitt multivibrator also appears in
transistorized form (Fig. 4-8). Its action is the
same as the tube version, except when operating in
the Automatic mode.

When the circuit is switched to automatic operation
by the Mode switch, Q2 conducts, its collector drops
abruptly about 5 volts and then drops more slowly
as C1 charges. See Fig. 4-9. The base of Q2 goes
negative until Q2 cuts off, causing an abrupt 5 V
rise and a slower rise in its collector voltage, as
C1 discharges. As the base of Q2 rises to the point
of conduction, Q2 turns on again, completing the cycle.
An input signal to Q1 will cause the multivibrator to
switch prematurely; and as the signal amplitude
increases it will override the free-running action.
The multivibrator will then trigger in the normal
manner, provided the input frequency is greater than
the automatic free-run frequency.
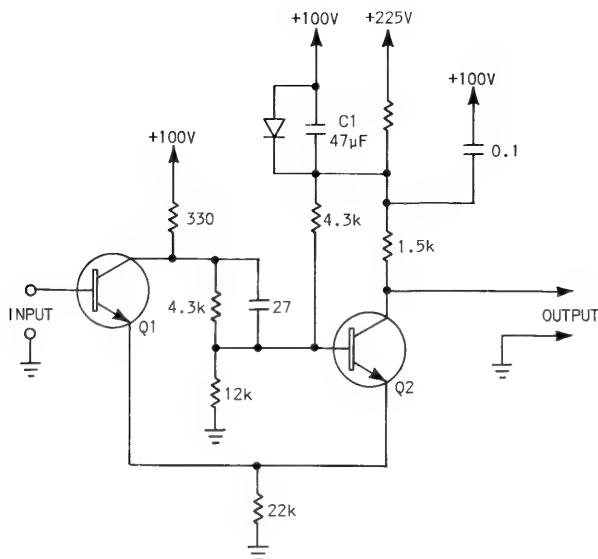
Fig. 4-8. Transistorized Schmitt multivibrator.
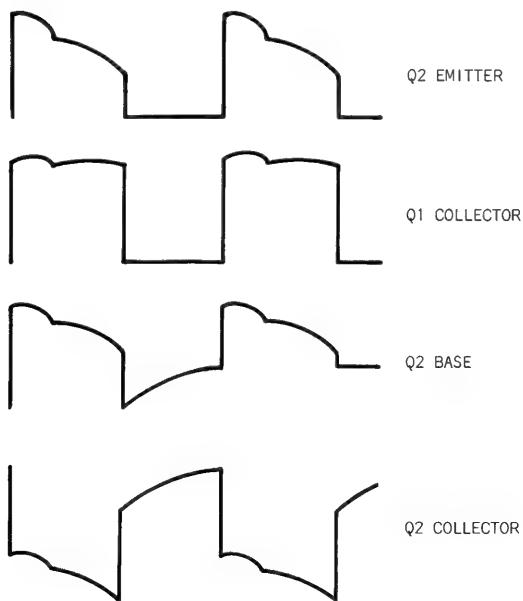
Fig. 4-9. Cycle of Schmitt multivibrator.
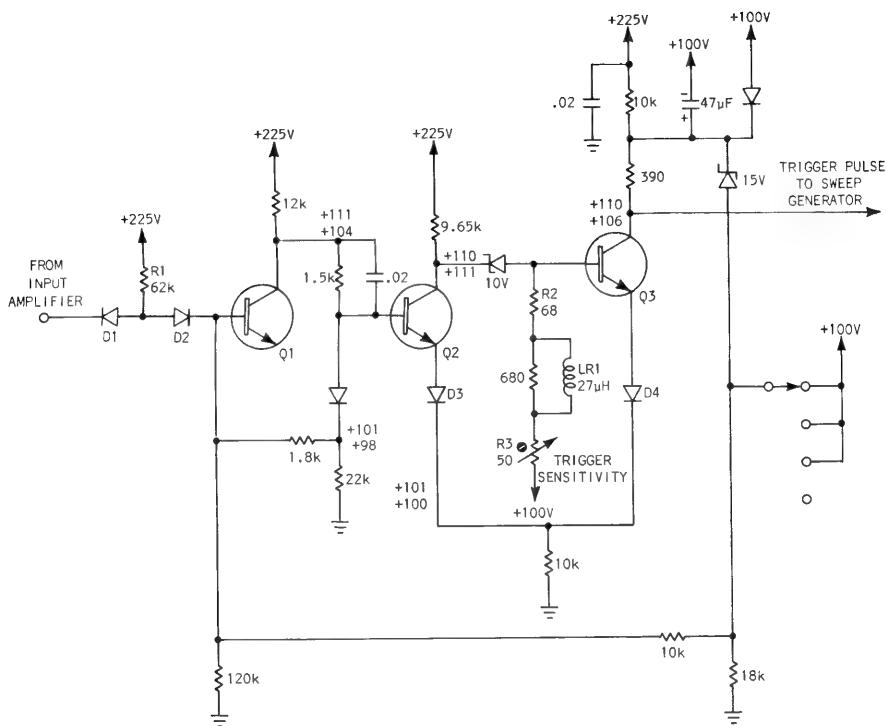
Fig. 4-10. High frequency Schmitt trigger.

HIGH-FREQUENCY COUNTDOWN ACTION

LOW-FREQUENCY ACTION
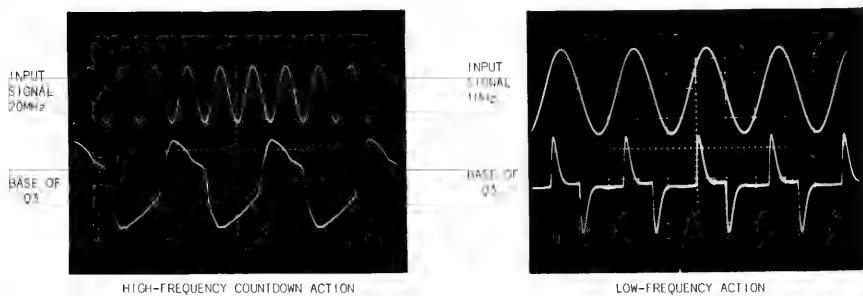
Fig. 4-11. High frequency countdown action
and low frequency action.

modified
transistor
Schmitt
multivibrator
In its transistorized version, the Schmitt multivibrator can be modified to provide stable triggering up to and beyond 30 MHz (Fig. 4-10). Additional circuitry causes it to ignore input pulses that arrive during its transition time (a process known as "countdown"), so that it produces one output pulse for every second, third, fourth, etc., input pulse. Its output frequency under these conditions is some submultiple of the input signal frequency.

Circuit operation is as follows: In the quiescent state diode D1 is forward biased, D2 is cut off and transistor Q1 (an operational amplifier) is biased below the conducting level. When the positive pulse from the input amplifier is applied, D1 disconnects and the junction between the diodes goes sufficiently positive to turn on D2. The increased drop across the base circuit turns on Q1, and the resulting negative collector signal is applied to the base of Q2, the first stage of the multivibrator. At high frequencies, this circuit then begins to count down to one of the succeeding pulses and its frequency becomes equal to some submultiple of the input frequency. See Fig. 4-11. Countdown begins at about 8 MHz. At these frequencies, Q2 collector load increases as inductance (L1) increases. The signal voltage swing at the base of Q3 increases to about 9 volts. The increased signal at the base of Q3 overdrives the transistor far beyond cutoff in the negative excursion and in the positive direction lifts Q3 emitter until Q2 is cutoff. Under these conditions the multivibrator cannot be driven until the LR time of LR1 returns the base of Q3 to its normal operating level. D3 and D4 are reverse breakdown protection diodes for Q2 and Q3.

However, since a large number of triggers are still generated in the interval occupied by even the fastest available sweep, countdown does not result in a loss of repetition rate.
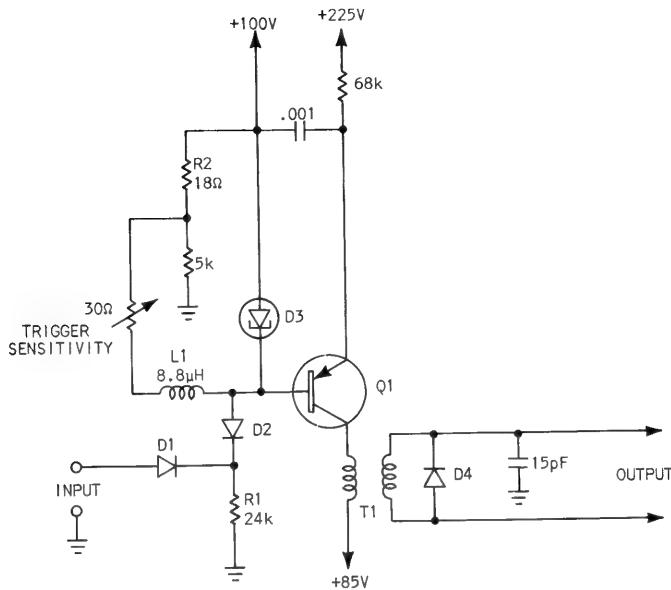
Fig. 4-12.   Tunnel diode pulse generator.
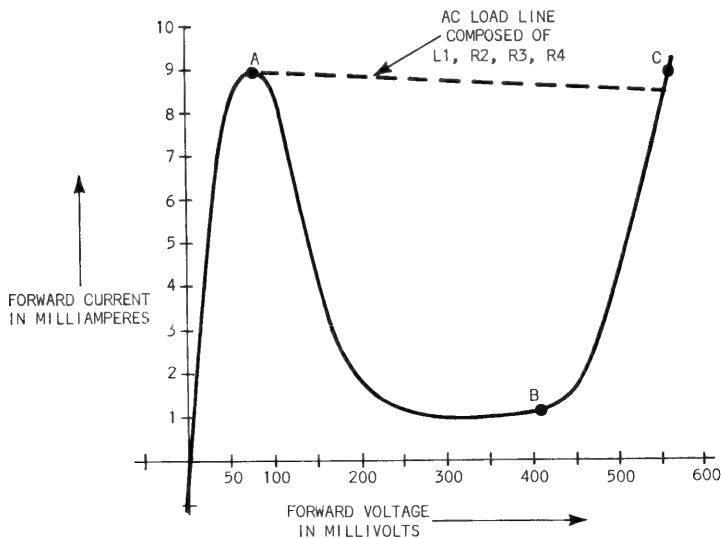
Fig. 4-13.   Tunnel diode characteristics.

tunnel diode pulse generator

The tunnel diode (TD) pulse generator permits triggered oscilloscope operations at extended high frequencies. It is characterized by its simple circuitry and its ability to operate on very fast low energy-input pulses. The TD pulse generator (Fig. 4-12) is used extensively in wide band oscilloscopes and permits triggered operation over the entire bandpass of the instrument. The tunnel diode pulse generator is preceded by an input amplifier using high transconductance (g_m) tubes to provide sufficient switching current for this mode. (Since it came into use before the modified transistorized Schmitt, the TD pulse generator may also be found in some relatively low frequency instruments.)

The Trigger Sensitivity control is set so that in the quiescent state about 9 mA of current passes through tunnel diode D3. The diode rests below point A on the first slope of the tunnel diode curve in Fig. 4-13. The input terminal is slightly positive and about 2 mA of current passes through diode D1. As the negative signal from the input amplifier cuts off D1, an additional 2 mA of current passes through D3 switching it to its high state, point C in Fig. 4-13. As the current through L1 increases, the current through D3 shifts down the tunnel diode curve to point B and rests conducting about 1 mA of current. When the input signal goes positive, D1 again conducts, the current through D3 is reduced, and D3 drops back to its low voltage state. The impedance of D3 in the low state is about 8 ohms, therefore the current increases to 9 mA, placing the operating point just below point A which completes the cycle. As the input frequency increases, inductor L1 causes current in R2 and R3 to lag, and the circuit begins to countdown. (Countdown usually occurs between 2 and 6 MHz, but higher input amplitudes may cause it to take place at higher frequencies.) The voltage change across the tunnel diode is about half a volt and may require amplification before being applied to the sweep generator circuit. Transistor Q1 performs this function, accepting the TD output and applying amplified pulses to the sweep generator circuit through transformer T1. Diode D4 is placed across T1's secondary winding to limit the output pulses to a single polarity and prevent ringing.
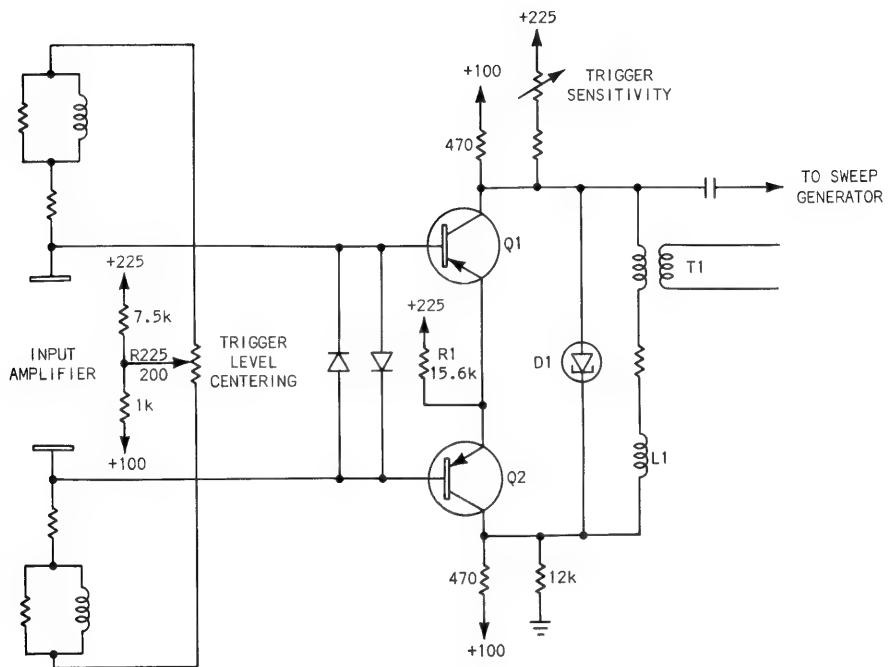
Fig. 4-14. Tunnel diode pulse generator
circuit with transistor driver.

The Fig. 4-14 illustrates another type of TD pulse generator which eliminates the need for high transconductance tubes in the input amplifier. Transistors Q1 and Q2 form a current amplifier, converting the push-pull output of the input amplifier to a current driving signal for tunnel diode D1. Maximum current is limited by long-tailed emitter resistor R1. The series inductance of L1 and T1, togehter with the output resistance, control the countdown frequency of the circuit.

NOTE: The second output from this pulse generator from T1 controls the action of a multivibrator in the associated sweep generator. In the absence of an output from transformer T1 (automatic mode), the sweep generator free runs, providing an untriggered sweep for the CRT. (For complete details, see volume on Sweep Generators.)
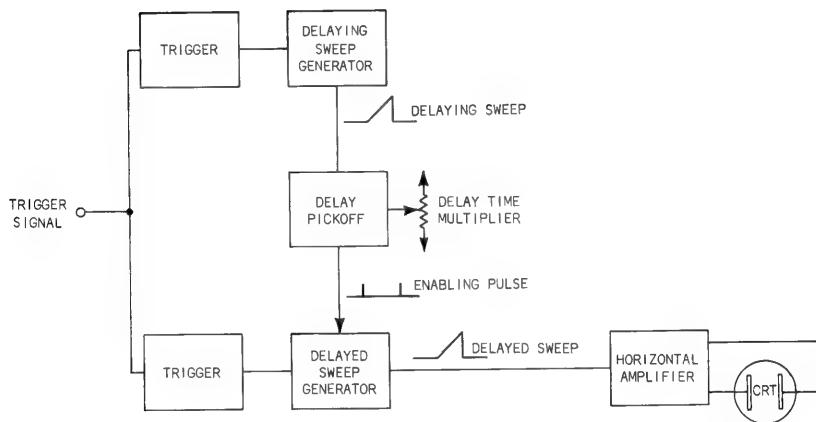
Fig. 5-1. Schematic for delayed sweep operation.

5

DELAYING AND DELAYED SWEEPS

delay
pickoff
circuits

Instruments with delayed sweep capabilities employ
a special trigger circuit called a "Delay Pickoff"
(Fig. 5-1). Its purpose is to start or enable a
second (delayed) sweep at a precisely controlled
time, measured from the start of the first (delaying)
sweep.

The following section on delaying and delayed sweeps
is developed around the triggering and gating circuits
involved. The discussion of circuits used to develop
the actual sweep waveform (sawtooth) is reserved for
the volume titled, "Oscilloscope Sweep Circuits."

delaying and
delayed
sweeps

Delaying-sweep measurements are based on the use of
two linear calibrated sweeps. The first sweep,
commonly called the delaying sweep, allows the
operator to select a specific delay time. When this
time is reached, the delayed sweep starts. The
delayed sweep on some instruments is faster than
the delaying sweep. It offers additional resolution
and increases the accuracy of time-interval
measurement.

To understand delaying sweep operation, it is
necessary to understand the time relationship between
the delaying sweep and the delayed sweep. To
illustrate, an event occurs, that starts the delaying
sweep at point t_0. The delaying-sweep voltage ramp
is applied to a voltage comparator, that produces
an enabling pulse later in time, t_1. This pulse
occurring at t_1 starts the delayed sweep. Then the
delay time may be defined as the difference in time
between the start of the delaying sweep and the
start of the delayed sweep and can be expressed as
$t_1 - t_0$. See Fig. 5-1, 5-2 and 5-3.

Before discussing how a delaying or delayed sweep is
generated, it would be wise to discuss applications
where they are useful.

There are three basic types of measurement that can
be made with a delaying sweep, arranged by order of
increasing accuracy, they are: (A) absolute delay,
(B) incremental delay, and (C) ratio measurements.

(A)   Absolute delay as shown in Fig. 5-4A is the
measurement of time from the start of the delaying
sweep to some point along the delaying sweep.

(B)   Incremental delay is the measurement of two
absolute delays and finding the difference between
them.   Fig. 5-4B.
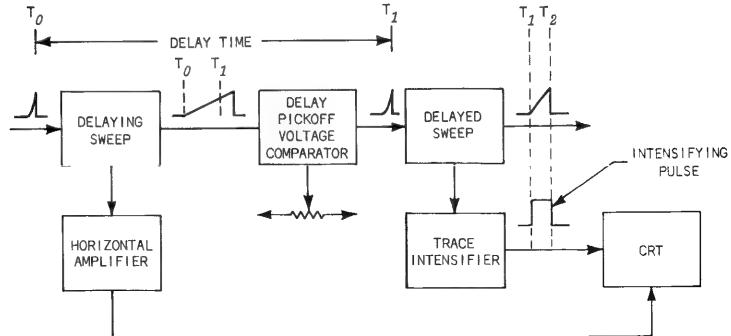
Fig. 5-2.   Schematic for delaying sweep
operation.
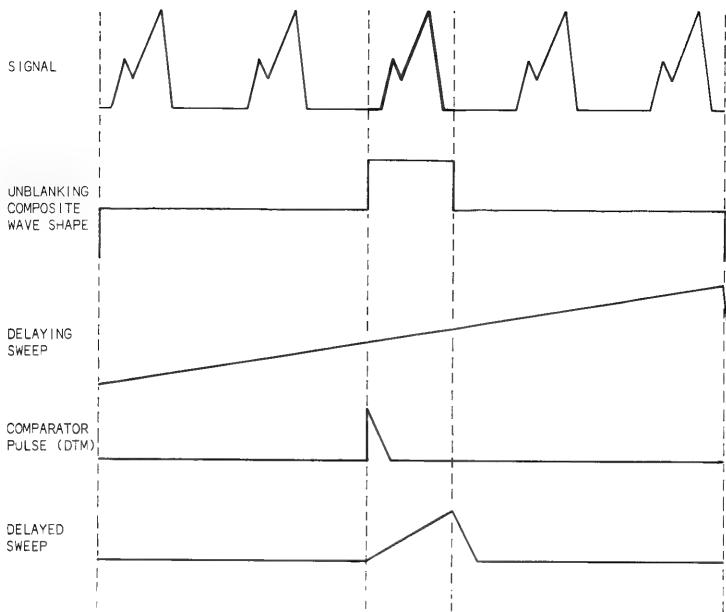
Fig. 5-3. Delaying sweep oscilloscope circuit
relationships.
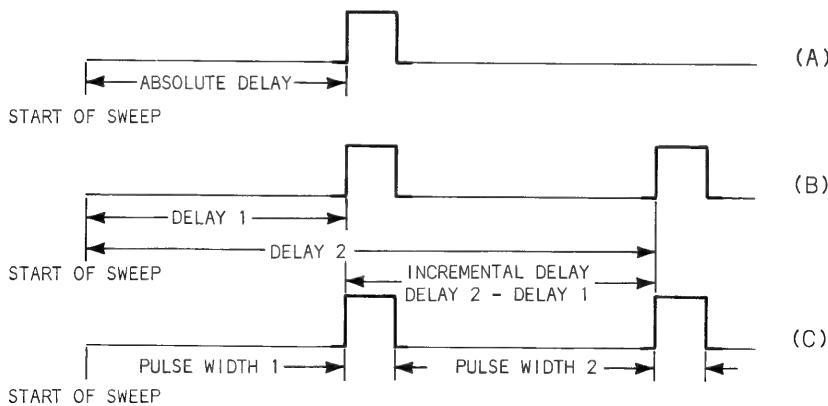
Fig. 5-4. The basic types of measurement using
delaying sweep techniques.

(C) A ratio measurement takes the ratio between two incremental delays. Fig. 5-4C.

delayed trigger

An absolute delay measurement may be made between two independent signals, one which externally triggers the sweep and one occurring later in time which is displayed. This mode may also be used to generate a delayed pulse to trigger another piece of equipment from the DELAYED TRIGGER output of the CRO. The accuracy of this type of measurement is limited by the processing time of the trigger signal, the slope of the trigger signal, the processing time of the pickoff circuit and the rate and linearity errors in the delaying sweep.

Except for the rate and linearity errors in the delaying sweep, the above errors are not particularly significant until one begins to use the faster sweep speeds (i.e. small absolute delay measurements). For most situations, this method of measurement of absolute delay is more accurate than making the measurement from the graticule.

delay time-multiplier potentiometer

The delaying sweep, Delay Time-Multiplier (DTM) potentiometer used to measure delay times, also offers greater resolution under most conditions, than just reading the delay times from the graticule. This improved resolution also applies when generating a delayed pulse as this allows more precise time interval settings.

A measurement made using the CRT graticule depends upon the oscilloscope's ability to line-up precision time-markers with major graticule divisions, and is subject to errors contributed by non-linearity in the horizontal amplifier and CRT. The delaying-sweep method uses the CRT as a null read-out device that does not affect the measurement accuracy.

An intensifying pulse applied to the CRT indicates when the delayed sweep starts with respect to the delaying sweep, so delay time can be determined independently of horizontal amplifier and CRT considerations. The portion of the delaying sweep that is intensified is a direct function of the duration of the delayed sweep as shown in Fig. 5-3.

error of
graticule
method

The possible error of the graticule method is
determined by the accuracy of the sweep as observed
on the graticule. With a specification of ±3% of
full scale, a measurement has a maximum possible
error of ±0.3 ms on the 1 ms/sec range. This type
of error is easy to calculate because the ±3%
specification normally includes both a timing or
rate error and a nonlinearity factor. The delaying-
sweep method also has these same basic factors which
contribute to possible errors, although they are
more complex in nature. Since the voltage ramp of
the delaying sweep is the time base used in the
delaying-sweep method, the basic sources of error in
time-interval measurements can be illustrated as
shown in Fig. 5-5.
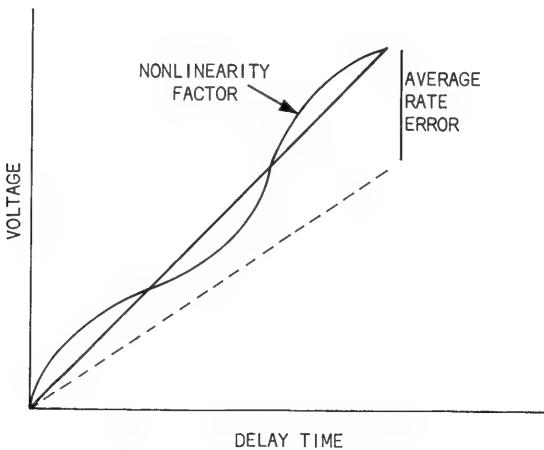
Fig. 5-5. Error in time-interval measurements.

The dotted line represents a no-error condition, while the linear solid line represents the average rate error due to differences of the timing networks nonlinearity in the delaying sweep. The nonlinearity factor varies about the solid line and represents the actual delay time read on the DTM. This nonlinearity factor is a combination of both sweep and potentiometer nonlinearity, and is usually expressed in terms of dial divisions on the DTM. Delaying-sweep percentage error is then calculated by using this figure and the percentage figure for rate error. Percentages of rate error are typically expressed in terms of actual delay time and are usually better than the sweep-rate accuracy as read on the CRT, because they do not depend on the horizontal amplifier and CRT.

Absolute delay is a measurement from the start of the sweep to the occurrence of an event.

Since the trigger circuit is a level selector, it is difficult to tell exactly where the point T_O is, especially when the triggering signal has an appreciable slope. The delay adjustment cannot be reduced to zero to check the start point and the accuracy of the delay start and stop adjustments affect the accuracy of the delay readings. There is also a time delay in the trigger circuit from the pickoff point in the vertical, to the starting point on the CRT. This delay may change as the triggering source is changed from main amplifier to plug-in triggering or to external triggering -- these delays are especially important at higher sweep speeds as they may become an appreciable part of the measurement.

Fixed delay is a result of inherent circuit delays fixed delay because the comparator requires time to generate a trigger pulse, and the delayed sweep and trace intensifier require time to generate an intensifying pulse. At these faster sweep rates, the delay time can be expressed as accurate within some percentage plus some fixed delay such as 100 ns. See Fig. 5-6.

One source of error mentioned is the delay time multiplier and is due to nonlinearities of the potentiometer resistance element and the mechanical linkages. The comparator itself, due to possible changes in firing threshold at various voltage levels, may contribute some error.
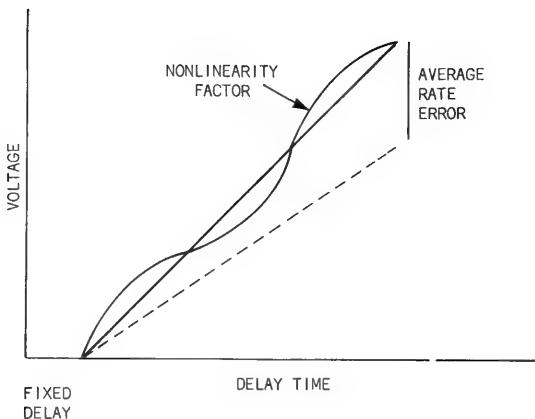
Fig. 5-6. Error in time-interval measurements
with fixed delay.

Incremental delay measurements are made between two
points along the delaying sweep. The time measurement
is the difference between two absolute delays. A
measurement of this type is typically made between
the leading and trailing edge of a pulse, the leading
edges of two pulses, or any two points of interest
along a waveform.

The example in Fig. 5-7 illustrates a typical
incremental measurement. Note the intensified portion
of the lower waveform which is displayed in magnified
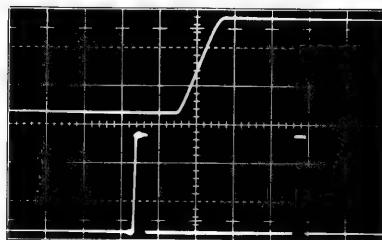
Fig. 5-7. Determining the delay time of
pulse 1.
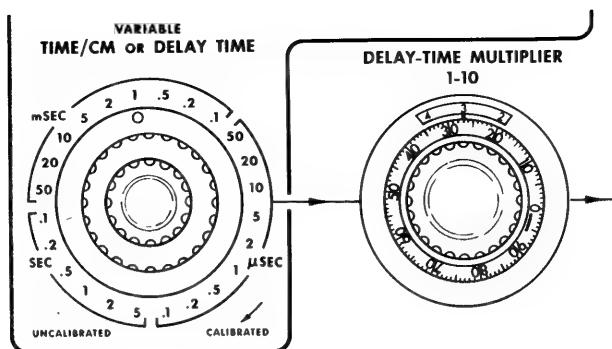
Fig. 5-8. Delay time reading
1 ms x 3.27 = 327 ms.
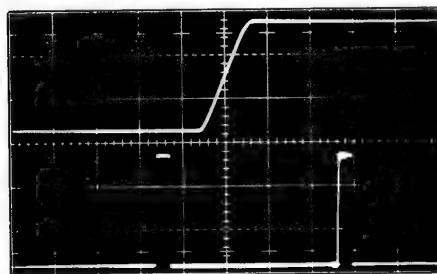
Fig. 5-9. Determining the delay time of
pulse 2.
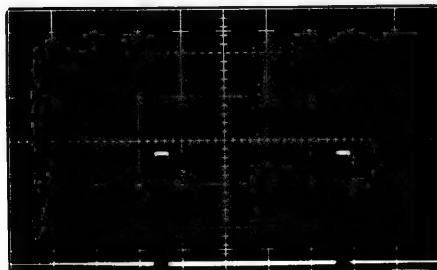
Fig. 5-10. Determining time between events by
graticule measurement.

DTM

form above it. The delay time associated with this event is determined by multiplying the delaying sweep rate of 1 ms by the DTM reading of 3.27, as shown in Fig. 5-8. By turning the DTM until the next event is intensified and the upper waveform is in the same relative graticule position as before, a display like Fig. 5-9 is seen. If the delay time of this event is 7.47 ms, then the time interval may be computed.

It is not necessary to determine the actual delay time of the start of the event, however, in both cases the DTM is adjusted until the magnified portion of both events is in the same relative graticule position. In the examples shown, the center (or 5-cm point) of the graticule is used. Any point on the graticule may be used as long as it is the same point for both events.

The difference between these two delay times is 4.20 ms and corresponds to the period of time between the two intensified events. Each minor division on the DTM represents 0.01 ms, which also represents the resolution of the delay time. Measuring with the graticule, the resolution is approximately 0.1 ms or reduced by a factor of ten. Fig. 5-10 shows the same two events with a sweep rate of 1 ms/cm.

In Fig. 5-10, each minor horizontal graticule division corresponds to 0.2 ms. The time between the two events, as read from the graticule, is 4.2 ms. When making a graticule measurement, only two numbers are significant because of the limitations in resolution due to trace width and display size. Thus the delaying-sweep method offers the additional resolution of an extra significant number.

By using the incremental measurement technique, the uncertainty of the measurement start point T_O is removed when the first measurement is subtracted from the second measurement.

$$(T_O - T_1) - (T_O - T_2) = T_2 - T_1$$

So T_O is no longer included in the computation, but the processing time of the trigger circuits is a constant and does not vary between measurements.

Error percentages are related to full scale readings
and therefore become a larger percentage of a small
measurement. If we say that a sweep accuracy is ±1%
this means that there may be an error of ±1 mm in ten
centimeters -- it also infers that there might be a
±1 mm error any place along the sweep and still be
within specifications.

incremental
measurement
technique

In making incremental measurements, it is found that
the error reduces at about the same rate as the
measurement and the 1% error is 1% of the measurement
made and not as great as 1% of full scale. The error
due to helidial nonlinearity is ±2 minor divisions,
however, and may contribute an error of 2% for a 1 cm
or a 1 major division measurement. This is a fixed
potentiometer linearity specification and becomes a
smaller part of the measurement as the measurement
is made over a larger portion of the CRT or delay
time multiplier dial range. Maximum error may then
be specified as:

$$= \pm(1 + \frac{2}{\Delta}) \%$$

1 The 1% accuracy of the sweep
2 The ±2 minor divisions of DTM pot linearity
Δ The actual difference reading in major
   divisions or DTM revolutions.

The error is graphically produced in Fig. 5-11.

Δ IS THE DIFFERENCE BETWEEN
TWO DELAY-TIME MULTIPLIER READINGS
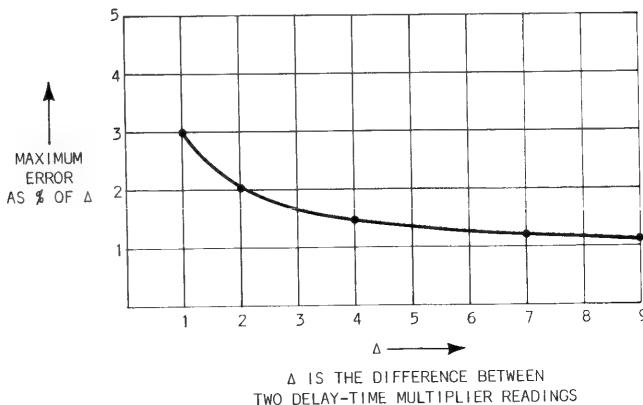
Fig. 5-11. Error when using incremental
measurement technique.

From the graph it becomes obvious that greater
accuracy is obtained by making a measurement over
as large a part of the graticule or delay time
control as possible to reduce the error contributed
by delay time potentiometer nonlinearity. It should
seldom be necessary to make a measurement less than
about 3 cm because the greatest next sweep speed
ratio will expand this to 8 cm by going to the next
higher sweep speed on the delayed sweep.

ratio   The most accurate delaying sweep measurement that
measurement   can be made is a ratio measurement.

Ratio measurements are made, when two time periods
such as two pulse widths are compared. This is
actually two incremental measurements. In this
mode, the results of the two incremental measurements
are compared $\frac{\text{Measurement } \#1}{\text{Measurement } \#2}$ and the ratio cancels out
the sweep speed times. The result, however, is no
longer a time measurement, but a ratio between the
two time periods. The exact time of each occurrence
is not used, but rather the ratio of one to the other.
This is quite accurate if measurement is made over a
large part of the Delay Time Multiplier dial.

It should be emphasized that all of these are worst
case errors and will typically be less in actual
practice. Delaying sweep accuracies are not ±1% on
all instruments which may make results vary from the
examples given. Specifications for the instrument
being used should be checked.

The resolution of these delay times can be improved,
thus improving the time-interval measurement accuracy,
by driving the horizontal amplifier with the delayed
sweep. The intensified portion of the delaying-sweep
presentation is now displayed over the full CRT
display. In the case of Fig. 5-3, this appears as a
10X magnified display since 1/10 of the original
waveshape time is now displayed over the same
graticule area. A delaying-sweep oscilloscope then
acts as a magnifier, whose magnification power is the
ratio of the delaying-sweep rate to the delayed-sweep
rate.

$$\text{Magnification} \qquad \frac{\text{delaying sweep rate}}{\text{delayed sweep rate}}$$

$$\frac{1 \text{ ms/cm}}{1 \text{ s/cm}} \qquad \text{(Sweep rates used are only examples)}$$

$$\frac{10^{-3}}{10^{-6}}$$

$$1000:1$$

Fig. 5-12 illustrates the use of delaying sweep to magnify a signal 1000X to allow closer examination of leading edge detail. Some oscilloscopes can provide a dual display of these two sweep rates. This is accomplished by using an internal multivibrator to switch between sweep rates and is referred to as automatic display switching.

When measuring short time intervals, it is not always possible to use the delaying sweep at a fast enough rate and still maintain a proper delaying sweep to delayed sweep ratio for the desired magnification. When this occurs, the graticule method may prove more accurate. After using the delaying-sweep method, simply multiply the measured time interval by the delaying-sweep rate accuracy (as in the graticule method) and use the most accurate figure. In most cases, the delaying-sweep method will be the more accurate way of making time-interval measurements.

improving accuracy

Accuracy can be further improved by using a time-mark generator to calibrate the DTM. By selecting time-marks so that accurate time-marks can be intensified and magnified for each ten major dial divisions, a calibration chart can be constructed for any delaying sweep rate that is needed.

The accuracy of this final measurement is limited only by the accuracy of the time-markers and the nonlinearity that occurred in 10 dial revolutions of the delay time multiplier dial. This accuracy can be held to about ±0.1%.
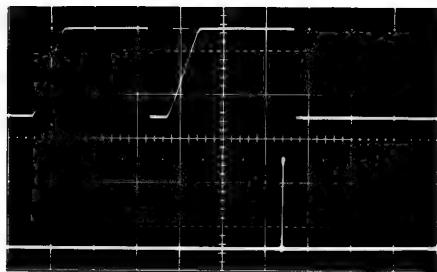
Fig. 5-12. Magnified 1000X display resolves two
            pulses from apparent single pulse.
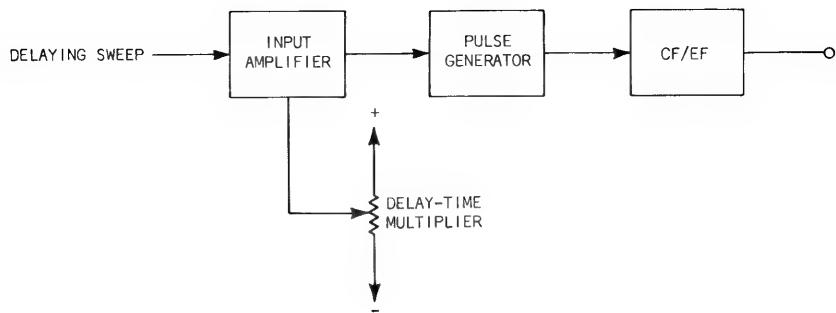
Fig. 6-1. Delaying sweep generator.
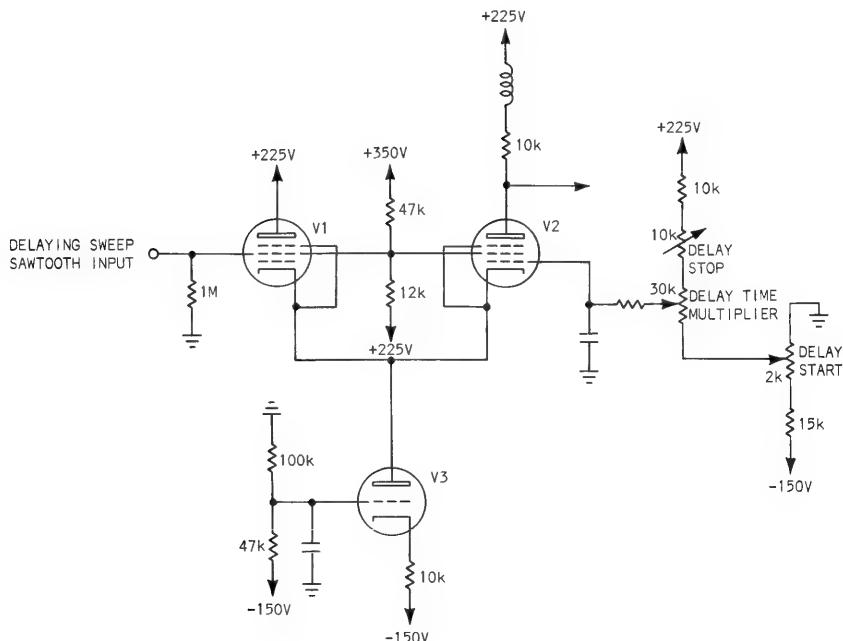
Fig. 6-2. Delay time multiplier and input
amplifier.

6

TRIGGERED DELAYED SWEEPS

In the type of operation just described, the delayed sweep is operated in a free running mode and starts when it receives an enabling pulse from the delay pickoff. If there is time jitter between the delaying sweep trigger signal and the signal viewed with the delayed sweep, it will be magnified by the ratio of the two sweep speeds.

time jitter   Sometimes it is useful to look at a signal that has time jitter and to be able to hold it stationary on the screen. Operation of the delayed sweep in a triggered mode allows this. With this configuration, the delaying sweep produces an enabling pulse in the normal manner, but the delayed sweep is only armed and will not sweep until it receives a trigger pulse from the delayed sweep trigger circuit. As a result, the delayed sweep starts with the observed pulse and is not time related to the pulse that triggered the delaying sweep. This causes a jittering pulse to appear jitter free. Precision time measurements using the delay time multiplier cannot be made in this mode because the time delay is only partially dependent on the delay time enabling pulse. When the display is observed in the B Intensified by A position of the Horizontal Display switch, the brightened part of the sweep will appear to jump from waveshape to waveshape as the Delay Time Multiplier dial is rotated.

triggering   The input signal to a Delay Pickoff is the sawtooth
level control output voltage supplied by the delaying sweep generator (Fig. 6-1). Since any point on the ramp of the sawtooth may represent the desired delay between sweep starts, the triggering level control (now called a Delay Time Multiplier) in the input amplifier must supply a range of voltage equal to the 10 major-division value, of the unattenuated sawtooth (Fig. 6-2). A multi-turn precision potentiometer is used for this purpose and its output is applied to the grid of V2.

Because the input amplifier must respond to such a wide range of input voltages, tube V3 is placed in the cathode circuit of V1 and V2 to provide a source of constant current.

delay
start/stop

Since the rate of rise of the input sawtooth is relatively low, the input amplifier is designed for high gain. The resulting high amplitude output signal results in more positive switching action in the pulse generator. No Trigger Level Center adjustment may be found in this circuit, but the Delay Start and Delay Stop adjustments perform the same function. The Delay Start potentiometer is adjusted so that the pulse generator produces an output when the input sawtooth has risen to 10% of its 10 major division voltage, and the delay time multiplier is set at a value of 1.00. The Delay Stop potentiometer is set to produce a pulse when

delay
start/stop
accuracy

the input sawtooth rises to 90% of its 10 major division value and the Delay Time Multiplier is set at 9.00. (These adjustments interact and require several adjustments for accurate delay timing). Each major division on the delay time multiplier now represents one-tenth of the delaying sweep time (one major division on the graticule). The accuracy of the delay pickoff circuit depends largely on the linearity of the delaying sweep sawtooth and the Delay Time Multiplier potentiometer.

input
amplifier

Fig. 6-3 is a schematic of a hybrid input amplifier, in which a transistor replaces the vacuum tube as a constant-current source.

delay
pickoff
circuit

Fig. 6-4 represents a fully transistorized delay pickoff circuit. Diodes D1 and D2 protect transistors Q1 and Q2 against Emitter-Base Junction reverse breakdown, when they are not conducting. Tunnel diode D3 acts as a pulse generator.
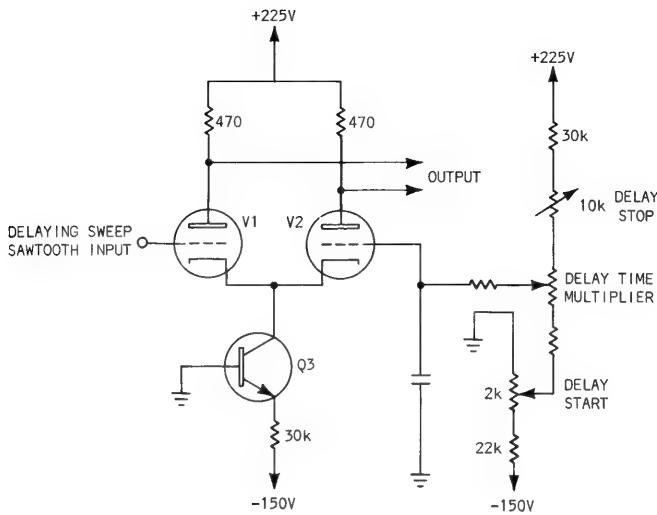
Fig. 6-3. Transistor/tube hybrid input amplifier.
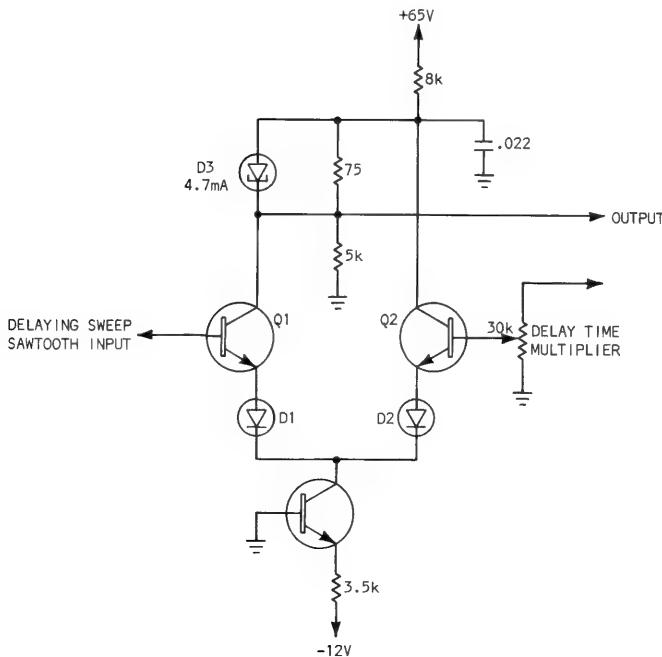
Fig. 6-4. Transistor delay pickoff circuit.

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A delay pickoff circuit may also utilize a Schmitt
pulse   multivibrator as a pulse generator (Fig. 6-5). Since
generator   the delayed trigger pulse is often made available at
              the front panel for use on external equipment, a
              low impedance output is required to prevent loading
low   of the pulse generator. Cathode follower V3 provides
impedance   this low impedance and, through the action of the
              coupling capacitor and resistors in its grid circuit,
              differentiates the delayed trigger pulse to provide
              a more narrow output pulse. The resistors are so
zero   selected that V3 is biased at cutoff, providing a
baseline   zero baseline voltage for the output pulse.

              In Fig. 6-6 a tunnel diode pulse generator is followed
              by an amplifying transistor. The emitter-follower
              configuration provides a low impedance output and,
              since it is not forward biased, also establishes a
              zero baseline voltage for the output pulse. The
              capacitors and resistors in the base circuit of Q5
              also form a differentiator to shape the output pulse.
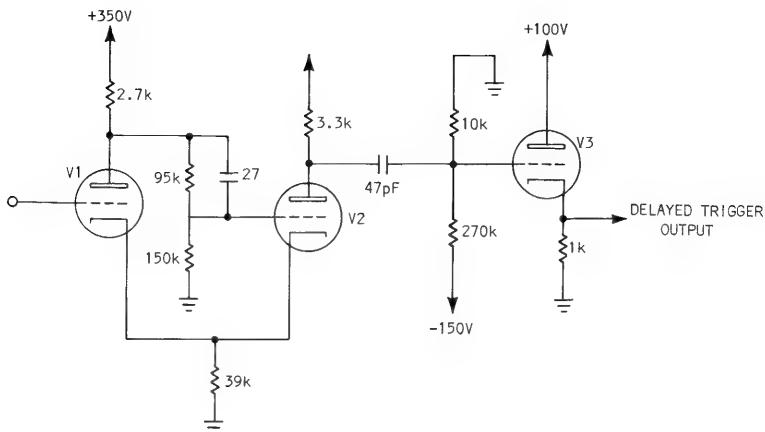
Fig. 6-5.   Schmitt trigger delay pickoff circuit.
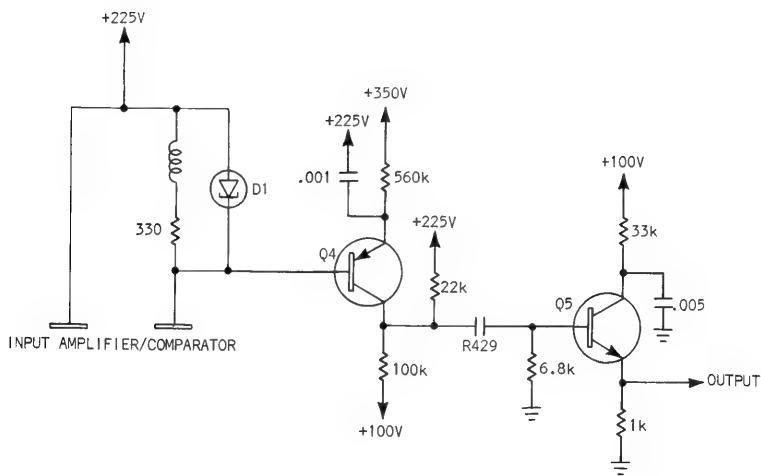
Fig. 6-6.   Low-impedance output from tunnel
diode pulse generator.

If the output of the emitter follower is fed back to the emitter of the amplifier, as in Fig. 6-7, the circuit becomes a monostable multivibrator. This circuit produces one output pulse of rapid and clear definition from one input pulse and operates as follows:

With no input, Q4 is conducting about 0.5 mA and Q5 is turned off with a negative 0.5 V on its base. A negative pulse from the tunnel diode turns Q4 on harder. A 12 V pulse from the collector of Q4 turns Q5 on, which feeds a 10 V pulse back to the emitter of Q4 and saturates Q4. The RC time of the feedback network between the emitters keeps Q4 saturated for about 1 μs before it reverts to the original state.
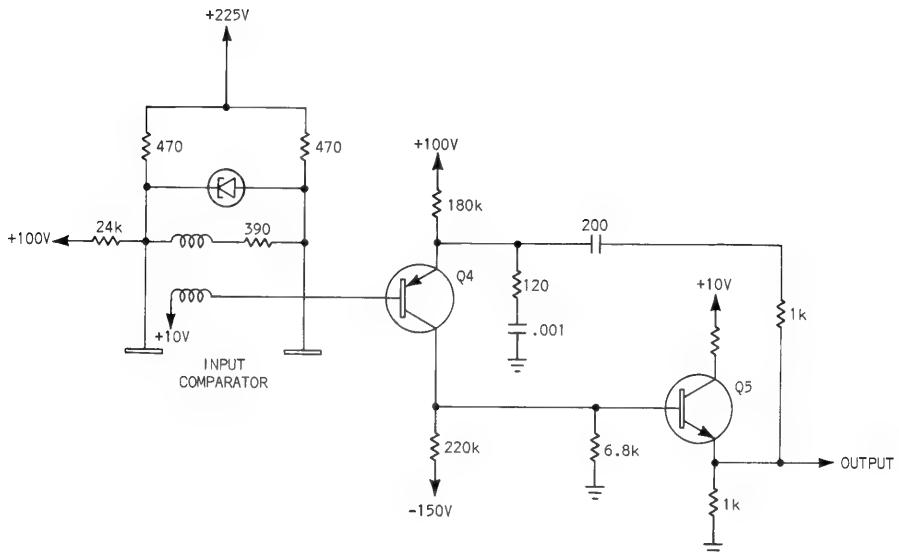
Fig. 6-7. Monostable multivibrator.

INDEX

CIRCUIT CONCEPTS
BY INSTRUMENT

Most concepts discussed in this book are applicable
to all Tektronix products containing a power supply.
However, the concepts listed on the following pages
are used in only certain products. Applicability is
indicated by a ● .

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	OSCILLOSCOPES:										
	310A	317	321A	422	453	454	491	502A	503	504	515
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Automatic Operation (p 49)	●	●	●	●	●	●		●	●	●	●
Delay Pickoff Circuits (p 59)					●	●					
Delay Pickoff Circuits, Transistorized (p 74)					●	●					
Delayed Sweep Accuracy (p 60)					●	●					
Hysteresis Adjustment (p 45)		●									●
Incremental Delay (p 60)					●	●					
Input Amplifier (p 22)	●	●	●	●	●	●	●	●	●	●	●
Ratio Measurement (p 62)					●	●					
Schmitt Multivibrator (p 43)	●	●	●					●	●	●	●
Single-Channel Amplifier Bandpass (p 12)					●	●					
Single-Channel DC Triggering (p 13)					●	●					
Single-Channel Takeoff Circuit (p 11)					●	●					
Synchronized Operation (p 21)	●	●						●			●
Trigger Coupling Circuit (p 15)	●	●	●	●	●	●	●	●	●	●	●
Trigger Level Centering (p 47)	●	●			●	●					●
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Triggered Delayed Sweep (p 73)					●	●					
Tunnel Diode Pulse Generator (p 55)					●	●	●				

PLUG-INS:

516	531A	533A	535A	536	543A	544	545B	546	547	549	551	555	565	581A	585A			M	T	1A1	1A2	1A4
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	3A72	3A74	3A75	3B2	3B3	3B4	3B5	3C66	10A1	10A2A	11B1	11B2A
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NOTES

NOTES

This book is but one of a series.
The series consists of two groups,
circuits and measurements. These
texts present a conceptual approach
to circuits and measurements which
apply to Tektronix products.
Several "concept books" are in
preparation; those now available
are:

Power Supply Circuits
062-0888-01

Oscilloscope Cathode-Ray Tubes
062-0852-01

Storage Cathode-Ray Tubes and Circuits
062-0861-01

Television Waveform Processing Circuits
062-0955-00

Information Display Concepts
062-1005-00

Semiconductor Devices
062-1009-00

Spectrum Analyzer Circuits
062-1055-00

Oscilloscope Trigger Circuits
062-1056-00